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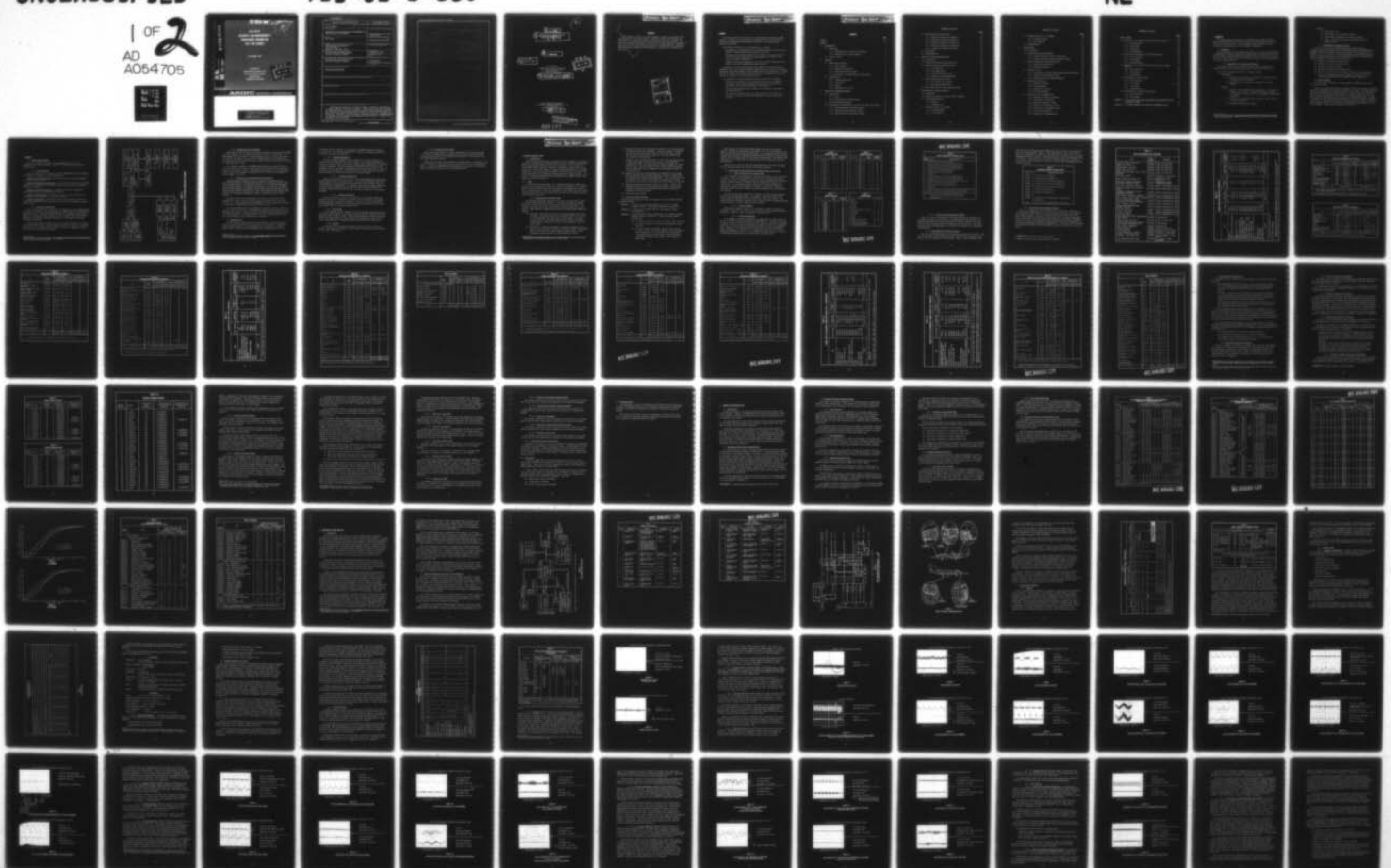

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FINAL REPORT

RELIABILITY AND MAINTAINABILITY IMPROVEMENT PROGRAM FOR THE F-106 AVIONICS

3 November 1967

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Prepared for
Warner Robins Air Materiel Area
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F09(603)-67-A-0003-0001

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9 FINAL REPORT

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ABSTRACT

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SUMMARY

This report presents the results of a 14-month program conducted by ARINC Research to improve the reliability and maintainability of the F-106 avionics. The work was performed for Warner Robins Air Materiel Area under Contract F09603-67-A-0003-0001.

The principal activities of this program were as follows:

- Development of recommendations for correcting equipment and human-factors problems defined during earlier contract activities
- Updating the F-106 model analysis and the report on the quantification of F-106 avionics reliability and maintainability to conform to the current equipment configuration
- Analysis of the power subsystem of the F-106 to define deficiencies and provide corrective recommendations where feasible

Updating of the F-106 quantification report and the F-106 model analysis demonstrated that the change in equipment configuration as a result of the Group II Interceptor Improvement Program did not degrade total system reliability. It also identified specific units, added during the modification program, that could be improved to increase the rate of mission success.

The findings of the power-subsystem evaluation include the following:

- Correction and expansion of test procedures can reduce the number of serviceable units rejected during bench check and the number of unserviceable units being bench-checked as serviceable.
- Certain minor modifications can improve unit reliability, performance, and maintainability.
- The addition of certain units and certain portions of the power subsystem to the periodic inspection requirement can reduce total system failures.

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1. INTRODUCTION

This report presents the results of a fifteen-month program, performed under Contract F09603-67-A-0003-0001, to improve the reliability and maintainability of the F-106 avionics. The objective of these improvements was to increase the effectiveness of the F-106 Fighter Interceptor.

1.1 Background

The work completed in this program was largely a follow-on to work performed by ARINC Research under the direction of Warner Robins Air Materiel Area in two earlier contracts, AF09(603)-48024 and AF09(603)-60655*. These earlier contract activities are described briefly in this report to provide a better understanding of the more recent activities.

1.1.1 Requirements of the Previous Contracts

The general objectives of the earlier programs were to maximize F-106 mission success, while minimizing repair time, at the lowest possible cost.

These earlier programs required the following actions:

- Investigate:
  - (1) Reliability on the basis of frequency of component failures and unsatisfactory performance
  - (2) Maintainability of components, subsystems, and overall avionics
- Perform:
  - (1) Deficiency area determinations, evaluations, and corrections through: (a) analysis of supplemental data and design, (b) redesign of circuits, and (c) improvement of maintenance techniques
  - (2) Reliability and maintainability analyses of ECPs submitted by other contractors
  - (3) Prototype and flight-test studies

*Final Engineering Report, Reliability and Maintainability Improvement Program for the F-106 Avionics, ARINC Research Publication 518-01-2-639, 19 July 1966.

- Evaluate:
  - (1) Modification tests
  - (2) Requirements for more effective support
  - (3) Minimum MTBF requirements for proposed equipment
  - (4) Impact of measured and predicted reliability values on mission success

1.1.2 Requirements of Current Contract

Under the current contract WRAMA, WRNE directed ARINC Research to "continue efforts initiated under Contract AF09(603)-48024 and AF09(603)-60655. Equipments previously analyzed did not contain Group II IIP (Rapid Tune and Paramp). In view of location of contractor personnel at organizations new operating with these modifications, the following services shall be accomplished against equipment containing Rapid Tune and Paramp:

(a) Updating of Measured Reliability Data

(b) Updating of Predicted Reliability Data

(c) Updating of Reliability Model

(d) Updating of Measured Maintainability Data

(e) Provide corrective actions to improve reliability where appropriate

(f) Review of maintenance procedures, analysis of adequacy of AGE and providing recommendations for improvement where appropriate."

1.2 Scope of Report

This final report discusses the tasks performed by ARINC Research during this contract period.

Section 2 outlines ARINC Research's approach, method, and reporting procedures. Supporting information and reliability standards are included. Problems associated with the implementation and quantification of the latter are given in Appendix A. Sections 3 and 4 present the complete results of updating tasks; Section 5, the power subsystem investigation; and Section 6, the human-factors study. A method to determine optimum troubleshooting strategy for a particular symptom is presented in Appendix B. Seven special tasks were completed during the course of this program. Complete results of the efforts have been previously submitted to the contracting agency. These tasks are presented in Section 7.

2. APPROACH

2.1 ARINC Research Methods

The scope of the F-106 contract allowed ARINC Research to use its experience in reliability research. Some of the basic concepts involved are discussed here.

2.1.1 Basic Approach

The five elements of the scientific method, ARINC Research's basic approach, are identified in Figure 2-1 and discussed below.

Element 1, Problem Definition: Pertinent data are collected and analyzed to define specific problems.

Element 2, Evaluation and Analysis: Once a problem is defined, more detailed analyses of the problem and its related equipment are performed to determine if a solution is possible.

Element 3, Solution Derivation: Alternate solutions are evaluated and quantified to select the optimum corrective action.

Element 4, Verification: The selected solution is first verified in the laboratory and then installed for operational testing.

Element 5, Refinement: During the course of the verification tests, the results are analyzed to determine whether the solution can be refined to achieve better results.

2.1.2 Reliability Prediction

Many reliability prediction techniques are currently in use by ARINC Research and others in the field. The technique used by ARINC Research for this program is consistent with the constraints and requirements of the program. Details of the prediction technique have been presented in special reports submitted by ARINC Research*, and additional information pertinent to this program is presented throughout this report.

The principal purpose of predictions in the earlier program was to indicate problem areas rather than to quantify equipment reliability exactly. The purpose of prediction in this program was to provide a baseline for comparing the pre-Group II and the post-Group II equipments.

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*ARINC Research Publication 329-01-1-492, Quantified Reliability and Maintainability Characteristics of the F-106 AWCIS, 1 March 1965.

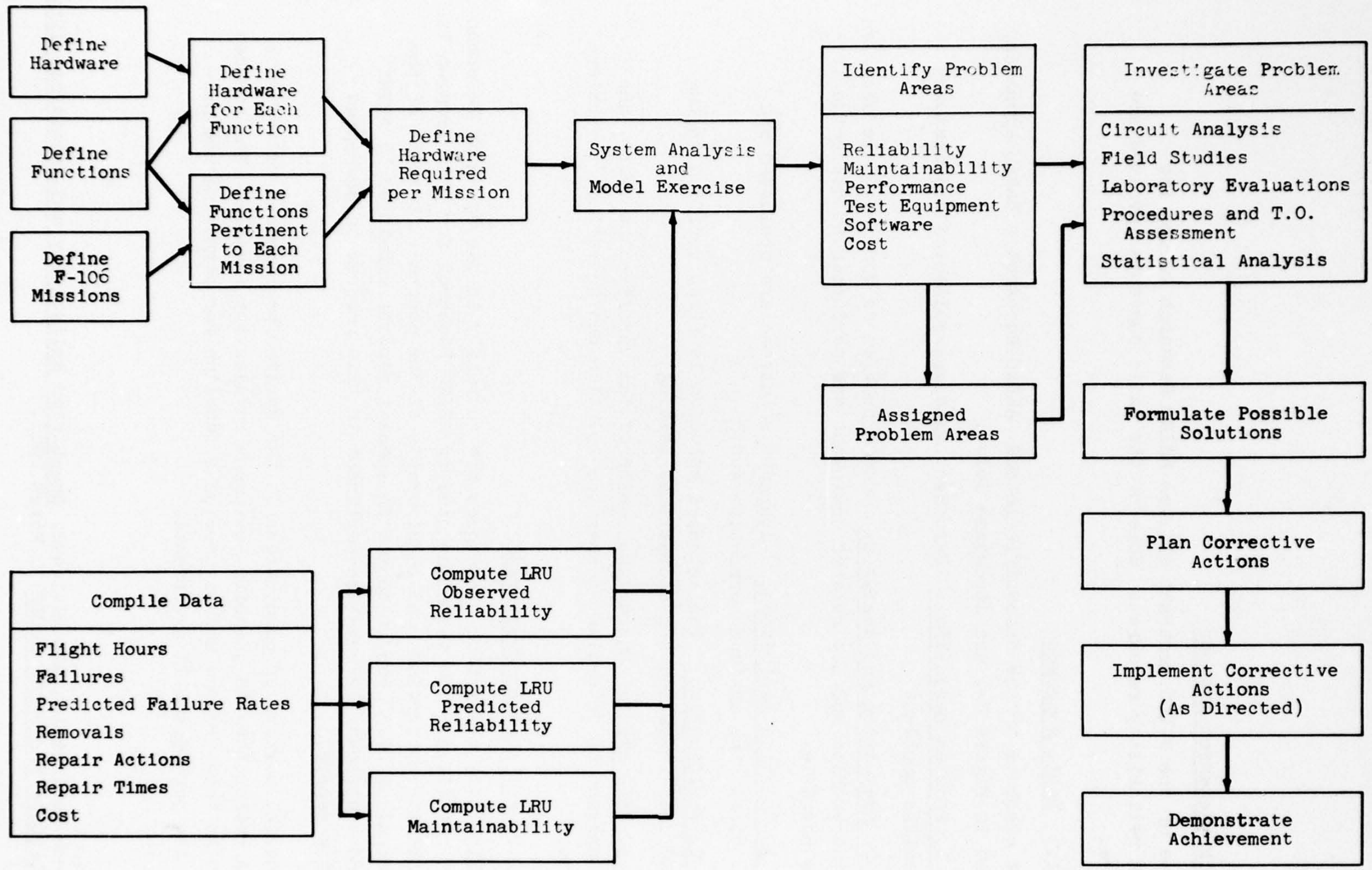

FIGURE 2-1

GENERAL METHODOLOGY FOR F-106 AVIONICS IMPROVEMENT PROGRAM

2.1.3 Computerized System Analysis

ARINC Research has developed a Computerized Reliability Analysis Method (CRAM) for machine analysis of the reliability indices of systems or subsystems. The CRAM program has the advantage of rapid execution once it is set up, particularly for iterative processes. By its nature, the CRAM program is less susceptible to the computational and translational errors usually associated with human processing of large quantities of data.

In the earlier contracts, the CRAM program was used in the F-106 avionics system to determine the relative influence of specific LRUs and their associated subfunctions on mission success. This approach was modified in the present application to provide the maximum information while still taking into consideration future changes in the F-106.

2.1.4 Reliability and Maintainability Measurements

The many problems associated with the collection and analysis of data to quantify reliability and maintainability indices of military systems are well known to ARINC Research. The principal problem is lack of detailed information and inadvertant errors in the AFM 66-1 data records. With this in mind, ARINC Research field engineers are required to cross-check data forms and correct them where necessary before transmitting the data. This approach, with frequent monitoring of the maintenance procedures, ensures a high-quality input for data analyses.

The quantification and interpretation of reliability indices are often misunderstood, usually because of the definitions of terms such as "time" and "failure" in a mean-time-between-failure (MTBF) index. This problem is discussed in some detail in ARINC Research Publication 518-01-2-639.

The measured MTBF values were contrasted with predicted values for LRUs of interest in the F-106 avionics. ARINC Research assumed that the predicted values represented an average, or state-of-the-art, value and developed a priority list for corrective actions. The desired result was thus a maximum increase in LRU (and system) MTBF for a given expenditure of resources.

2.2 Implementation

The basic methods discussed above were implemented to the extent possible within the typical constraints, time and money, of the contract. In addition, ARINC Research operated on a noninterference and a nonduplication-of-effort basis -- that is, the activities of ARINC Research conformed to and in no way

*ARINC Research Publication 329-01-1-492, Quantified Reliability and Maintainability Characteristics of the F-106 AWCIS, 1 March 1965.

interfered with the operation of the military, and ARINC Research coordinated all actions with the contract administrator to ensure no inadvertent duplication of efforts involving other agencies.

2.2.1 Program Organization

The basic program organization was substantially the same throughout the earlier two-year program and the present program. The program administration and primary engineering responsibility were at ARINC Research headquarters in Annapolis during both programs. The field-engineering and data-collection efforts were performed at Dover, Selfridge, and Langley Air Force Bases during the two previous contracts. The availability of modified aircraft dictated that Dover Air Force Base and Tyndall Air Force Base be used in the current program.

2.2.1.1 Field-Base Operations

ARINC Research personnel at the field bases operated under the technical and administrative control of the home office. At the F-106 operational bases these field personnel collected maintenance and operational data, verified them, and transmitted them to headquarters. In addition, they performed special tasks such as bench testing, developing proposed modifications, measuring temperature or performance, monitoring flight-tests, and interviewing operators and maintenance personnel.

2.2.1.2 Laboratory Analysis

Laboratory analysis of some of the equipment of the F-106 MA-1 AWCIS was necessary as part of the improvement program. This was performed in the ARINC Research laboratory at Annapolis, Maryland. The rest of the work performed at the ARINC Research laboratory included fabrication and checkout of the in-flight tape recorder used in the power-subsystem study.

2.2.2 Data System

The data systems employed throughout the F-106 programs were based primarily on available data sources. For example, the reliability and maintainability data system was based on AFM 66-1 data. ARINC Research engineers checked the data for validity and completeness and, where required, supplemented the data with additional information such as equipment-operate time and aircraft flight time.

2.2.3 Reports

The progress of the program was reported by means of monthly and special reports. The frequency and format of these reports conformed with the preferences of the contract administrator.

2.2.4 Coordination Activities

Administrative and technical liaison requirements were fulfilled through close contact of ARINC Research headquarters and resident personnel with the contracting agency and with other agencies participating in the overall F-106 MA-1 AWCIS improvement program.

Administrative liaison was maintained with Warner Robins. Coordination with other contractors was maintained through the Warner Robins Service Engineering group. In addition, ARINC Research attended and participated in all Technical Advisory Group (TAG) meetings held since September 1964.

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3. REVISION OF MATHEMATICAL MODEL

3.1 Introduction

Since July 1964 ARINC Research Corporation has been engaged in a program to improve the reliability and maintainability of the MA-1 Aircraft Weapons Control and Intercept System (AWCIS) as used in F-106 aircraft. As an aid to this study, ARINC Research personnel developed a mathematical model* of MA-1 system reliability. Since then, however, the model has become obsolete as a reference standard because of extensive modifications to the avionics of the F-106. The current MA-1 system is no longer the system portrayed in earlier reports. As a result, in August 1966, Warner Robbins Air Materiel Area (WRAMA) directed ARINC Research to re-assess the MA-1.

3.1.1 Goals

This new task has three goals: (1) a comparative measure of system, subsystem, and unit reliability of the new (Group II) configuration; (2) establishment of a new reliability-index base line (based on the current MA-1 system); and (3) identification of those Line Replaceable Units (LRUs) within the various subsystems that with the least modification will provide the greatest potential gain in system reliability.

3.1.2 Recapitulation of Earlier Work

The following paragraphs summarize the results of previous work in which the original mathematical model was used. This work was assigned to ARINC Research in October 1964 by the F-106 Technical Advisory Group (TAG). Computations were based on in-house data and data collected especially for the program. ARINC Research's Computerized Reliability Analysis Method (CRAM) was employed:

(1) Functional reliability profiles for the F-106A weapons system were developed. This required selecting "standard" missions on the basis of their importance and being typical of their group. The times selected for the various phases were average rather than maximum or minimum figures; they were not related to the capability limits of the aircraft.

(2) Functions (or elements) necessary for successful completion of each phase of each mission were defined. Here again "standard" requirements had to be selected from a great number of possibilities. If the requirement occurred rarely, the function was not included.

* Analysis of the Reliability Model for the MA-1 AWCIS of the F-106A Aircraft, ARINC Research Publication 329-01-1-491, 1 March 1965.

(3) The LRUs involved in each function were defined, and the LRUs required for mission success were identified. Only LRUs in which a substantial portion of the circuitry was related to the function were included. Units contributing only small items (e.g., one relay contact) were not included in that function.

During the unit-identification effort, it was found that approximately 13 LRUs were common to more than one function. These LRUs were separated from their functions during the computer program and treated as a function. For calculations in which relative answers were sufficient, these LRUs were not separated, thus increasing the speed of the calculations.

(4) Operation and failure characteristics were established for each LRU. The only functions with redundant LRUs were function U (command UHF) and function ADF (Automatic Direction Finder). For all other functions, the probability of success was defined as the product of the probabilities of success for the individual LRUs that comprise the function.

(5) Boolean expressions for mission success were devised. Symbols were assigned to each function, and subscripts were added to the symbols to denote the phase. These expressions were solved to obtain the probability of mission success.

(6) The results were analyzed.

3.2 Selecting Standard Missions

The following were selected (with the approval of the Air Defense Command) as standard missions:

Mission A - a high-altitude intercept mission (also called a standard recommit mission). Two different targets are intercepted.

Mission B - a low-altitude intercept mission. Two different targets are intercepted.

Mission C - a flush-intercept mission, combined with two standard recommit missions (similar to mission A). There are three stages in this mission:

(1) An aircraft takes off, hovers for a certain time, and lands.

(2) It takes off again for a high-altitude intercept mission and lands.

(3) It takes off again for another high-altitude intercept mission and lands. During the landings, fuel and armament may be replaced; but it is assumed that no maintenance is performed and no failures occur. Ground time during intermediate landing is not counted in the cumulative phase time.

Each mission is divided into several phases; and each phase requires specific functions to be successful (see Section 3.3). The time period for each phase was selected from numerous possibilities. Six experienced pilots at Dover Air Force Base assisted by completing questionnaires indicating the maximum time, minimum time, and average time for each phase in each mission. The time for each phase used in the calculations was the mean value of the typical time on the questionnaires.

Tables 3-1, 3-2, and 3-3 list the mission phases, the time for each phase, and the cumulative phase time for each of the three missions.

3.3 Determining the Requirements for Successful Phase and Function

3.3.1 Functions Required for Phase Success

It is difficult to determine which functions are essential to the success of each phase. Under some circumstances, every function is necessary for phase success; under other circumstances, none of the listed functions influence phase success, although function A (armament) appears absolutely necessary to the launch phase. As a compromise measure, only those functions necessary for launching all weapons in the majority of possible circumstances (especially those most useful in practice flights for which substantial data are available) are included.

It would not have been surprising if different missions required different functions for corresponding phases. For example, a low-level mission might require different equipment from that required by a high-level mission. The calculations were simplified, however, when it was found that corresponding phases required identical functions regardless of the mission.

3.3.1.1 Function Symbols

Symbols were assigned to each of the functions, to permit a concise presentation of functions in the tables, and to facilitate working with the Boolean expressions. Table 3-4 lists the symbols for the functions.

3.3.1.2 Boolean Expressions

As an example of a Boolean expression, T_{15} represents the premise that the function T (TACAN) operated successfully through phase 15. This type of notation (a capital letter to indicate the function and a numerical subscript to represent the phase) is used in a Boolean expression to describe a mission in mathematical terms. Table 3-5 shows each phase of Missions A and B and the corresponding Boolean expression. By arranging the 15 expressions according to the rules of elementary mathematical logic, it is also possible to show in Table 3-5 the concluding Boolean expression that can be equated to mission success.

TABLE 3-1 MISSION A PHASE TIME			
Number	Phase	Phase Time (Minutes)	Cumulative Phase Time (Minutes)
1	Climb	11	11
2	Vector	15	26
3	Offset	0	26
4	Acquire	3	29
5	Track	2	31
6	Launch	0	31
7	Pullout	1	32
8	Vector	14	46
9	Offset	0	46
10	Acquire	3	49
11	Track	2	51
12	Launch	0	51
13	Pullout	1	52
14	Return	17	69
15	Land	6	75

TABLE 3-2 MISSION B PHASE TIME			
Number	Phase	Phase Time (Minutes)	Cumulative Phase Time (Minutes)
1	Climb	4	4
2	Vector	15	19
3	Offset	0	19
4	Acquire	3	22
5	Track	1	23
6	Launch	0	23
7	Pullout	1	24
8	Vector	13	37
9	Offset	0	37
10	Acquire	3	40
11	Track	1	41
12	Launch	0	41
13	Pullout	1	42
14	Return	17	59
15	Land	6	65

TABLE 3-3 MISSION C PHASE TIME			
Number	Phase	Phase Time (Minutes)	Cumulative Phase Time (Minutes)
1	Climb	10	10
2	Loiter	44	54
3	Return	18	72
4	Land	7	79
5	Climb	11	90
6	Vector	14	104
7	Acquire	3	107
8	Track	1	108
9	Launch	0	108
10	Pullout	1	109
11	Vector	13	122
12	Acquire	3	125
13	Track	1	126
14	Launch	0	126
15	Pullout	1	127
16	Return	16	143
17	Land	7	150
18	Climb	11	161
19	Vector	14	175
20	Acquire	3	178
21	Track	1	179
22	Launch	0	179
23	Pullout	1	180
24	Vector	13	193
25	Acquire	3	196
26	Track	1	197
27	Launch	0	197
28	Pullout	1	198
29	Return	16	214
30	Land	7	221

TABLE 3-4 FUNCTION SYMBOLS	
Function	Symbol
TACAN	T
Command UHF	U
Data Link	D
Computer	C
MA-1 Power	P
Identification Friend or Foe (IFF)	I
Search Radar	SR
Track Radar	TR
Infrared	IR
Armament	A
Automatic Direction Finder	ADF
Instrument Landing System	L
Flight Control and Measurement (Automatic Flight Mode)	F

TABLE 3-5

BOOLEAN EXPRESSIONS FOR MISSIONS A AND B

Phase Number	Phase	Boolean Expression
1	Climb	P_1 & F_1 & C_1 & I_1 & $(U$ <u>or</u> $D)_1$
2	Vector	P_2 & F_2 & C_2 & I_2 & U_2 & D_2 & SR_2 & IR_2 & T_2
3	Offset	P_3 & F_3 & C_3 & I_3 & U_3 & D_3 & SR_3 & IR_3 & T_3
4	Acquire	P_4 & F_4 & C_4 & I_4 & U_4 & D_4 & TR_4 & IR_4 & T_4
5	Track	P_5 & F_5 & C_5 & TR_5 & IR_5 & A_5
6	Launch	P_6 & F_6 & C_6 & TR_6 & IR_6 & A_6
7	Pullout	--
8	Vector	P_8 & F_8 & C_8 & I_8 & U_8 & D_8 & SR_8 & IR_8 & T_8
9	Offset	P_9 & F_9 & C_9 & I_9 & U_9 & D_9 & SR_9 & IR_9 & T_9
10	Acquire	P_{10} & F_{10} & C_{10} & I_{10} & U_{10} & D_{10} & TR_{10} & IR_{10} & T_{10}
11	Track	P_{11} & F_{11} & C_{11} & TR_{11} & IR_{11} & A_{11}
12	Launch	P_{12} & F_{12} & C_{12} & TR_{12} & IR_{12} & A_{12}
13	Pullout	--
14	Return	P_{14} & F_{14} & I_{14} & [(ADF & U) <u>or</u> (D & C) <u>or</u> (SR & C) <u>or</u> $(T$ & $C)]_{14}$
15	Land	P_{15} & F_{15} & I_{15} & U_{15} & [(SR & C) <u>or</u> (T & C) <u>or</u> $L]_{15}$
Success = P_{15} & F_{15} & I_{15} & U_{15} & [(SR & C) <u>or</u> (T & C) or $L]_{15}$ & [ADF <u>or</u> [C & (D <u>or</u> T <u>or</u> $SR)]]_{14}$ & C_{12} & TR_{12} & IR_{12} & A_{12} & D_{10} & T_{10}		

3.3.1.3 <u>Tabulation of Functions and Phases</u>

Table 3-6 lists the combination of functions required for successful completion of each phase of the missions. The ampersand (&) indicates that the requirement applies to both of the functions it connects, while the "or" indicates that the requirement applies to either one of the functions. The entire expression within the parentheses is affected by the symbols (&, or) preceding the parentheses.

3.3.2 <u>LRUs Required for Function Success</u>

Each of the functions depends on the successful operation of its LRUs. Some LRUs are necessary for more than one function; others are not necessary to any function (for the completion of the missions). Many of these unnecessary LRUs

are used only for testing during maintenance and are not shown in the reliability model for an operating MA-1 system. Other LRUs normally listed in F-106 documents but omitted from this model are those used only on aircraft with the cockpit configuration known as "round." Other aircraft have a cockpit configuration known as "vertical." This study used the vertical configuration, which is common to 80 percent of the F-106 aircraft. Table 3-7 lists the LRUs intentionally omitted from all functions.

TABLE 3-6
RELATIONSHIP OF FUNCTION TO MISSION PHASES

Phase	Required Functions
Climb	P & F & C & I & (U <u>or</u> D)
Loiter	P & F & C & I & (U <u>or</u> D) & T
Vector	P & F & C & I & U & D & T & SR & IR
Offset	P & F & C & I & U & D & T & SR & IR
Acquire	P & F & C & I & U & D & T & TR & IR
Track	P & F & C & TR & IR & A
Launch	P & F & C & TR & IR & A
Pullout	
Return	P & F & I & (U & ADF) <u>or</u> (D & C) <u>or</u> (SR & C) <u>or</u> (T & C)
Land	P & F & I & U & L <u>or</u> (SR & C) or (T & C)

3.3.3 Failure Rates for Functions and LRUs

Tables 3-8 through 3-20 list the LRUs for the 13 functions. Tables for those functions not affected by the Group II program* are shown as they appeared in the original report. They list the observed failure rate for each of the LRUs, the percentage of the function failure rates, and the possible improvement ratio for each LRU. The tables for functions affected by the Group II program** present data on both the observed and predicted failure rates for comparisons of the Pre- and Post-Group II equipment configurations. Each function and the related data (Tables 3-8 through 3-20) are discussed in detail in Section 3.4.4 of this report.

* Tables 3-8, 3-9, 3-10, 3-13, 3-18, and 3-19.

** Tables 3-11, 3-12, 3-14, 3-15, 3-16, 3-17, and 3-20.

TABLE 3-7

LRU'S NOT INCLUDED IN THE FUNCTIONS

LRU	Part Number	Remarks
Digital Computer Test Set	464296	Used for self-test
Radar Test Set No. 1	464096	Used for self-test
Photographic Recorder	464149	Used for self-test
Radar Test Set No. 2	464196	Used for self-test
Electrical Equipment Rack, Photo Recorder	464702	Used for self-test
Dehydrator Rack	464674	Similar to P/N 464774
Rate Gryoscope Transmitter	TRU/2/A	Replaced by P/N 131311-01
Tactical Display Horizontal Situation Indicator (HSI)	464180	Replaced by P/N's 464181 and 464920
Vertical Situation Amplifier	464306	Round configuration only
Air Data Signal Data Converter (SDC)	464823	Round configuration only
Command and Target Altitude Indicator Assembly	464980	Round configuration only
Mach Number Indicator Assembly	464880	Round configuration only
Bar Setting Analog Signal Control	464259	Round configuration only
Static Pressure and Angle-of-Attack Air Data Compensator	464521	Round configuration only
SDC - Flight Director	464720	Round configuration only
Electrical Equipment Rack - Flight Director	464511	Round configuration only
Horizon Indicator	329B3	Round configuration only
Course Indicator	331A3	Round configuration only
Steering Computer	562A3B	Round configuration only
Radio Frequency (RF) Transmission Line Switch	464263	Disconnected
Liquid Level Indicator	464281	Used for self-test
Airborne Moving Target Indication (AMTI) Video Amplifier	464495	Disconnected
AMTI Signal Comparator	464150	Disconnected
Pressure Meter	464024	Used for self-test
AC-DC Generator	464089	Replaced by P/N 464056
Voltage Regulator Assembly	464992	Similar to P/N 464892
Infrared (IR) Range Unit	464746	Not necessary in this model
Non-Computing Fixed Sight	464169	Not used in these missions

TABLE 3-8

FAILURE RATES FOR TACAN LRU'S (FUNCTION T)

LRU	Part Number	Observed Failure Rate*	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
Antenna	2248	**	-	10.00	-
TACAN Receiver-Interrogator	464129	17,957.35	20.4	12,801.82	1.4:1
Rack	464074	4,489.34	5.1	161.18	27.8:1
TACAN Channel Selector Control	464405	4,115.23	4.6	647.25	6.4:1
TACAN Range Transmitter	464329	8,230.45	9.4	4,187.99	2.0:1
TACAN Bearing Transmitter	464429	9,352.79	10.6	4,565.95	2.1:1
TACAN Modulator Coder	464229	16,086.79	18.3	8,069.51	2.0:1
Cockpit Display No. 1 SDC	464520	2,992.89	3.4	12,413.26	-
Cockpit Display No. 2 SDC	464620	2,244.67	2.6	7,903.22	-
Tactical Display HSI	464181	13,468.01	15.3	19,229.66	-
Tactical Display Converter	464920	7,856.34	8.8	5,716.02	1.4:1
Rack	464602	227.40†	0.3	10.00	22.7:1
TACAN Indicator	ID-250	119.42	0.1	50.00	2.4:1
HSI Indicator	522-2411	748.22	0.9	5,363.83	-
HSI Amplifier	522-1394	250.13	0.2	433.34	-
Total		88,139.03		81,563.03	

* Failures per million hours.

** No data available.

† Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months) and modified to 80% because of use in only 80% of aircraft that have a vertical configuration.

TABLE 3-9 FAILURE RATES FOR COMMAND UHF LRU'S (FUNCTION U)					
LRU	Part Number	Observed Failure Rate	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
UHF Receiver, or	464167	50,505.05	2.0*	11,036.96	4.6:1
Time Division Data Link (TDDL) Receiver	464667	8,230.45	0.3	8,676.04	-
Frequency Selector Control	464505	13,468.01	18.2	1,460.76	9.1:1
Power Supply	464392	11,597.46	15.7	3,652.44	3.2:1
UHF Transmitter	464059	29,554.81	39.9	8,750.06	3.4:1
Rack	464074	4,489.34	6.1	161.18	27.9:1
Audio and ADF Electronic Control Amplifier (ECA)	464606	3,367.00	4.5	4,946.78	-
UHF Antenna and Lead	74524	9,523.81	12.9	-	-
Headset, Microphone, Personal Leads	96100	285.71**	0.4	-	-
Total		74,000.00		23,500.00	

* These represent the calculated contribution to apparent overall failure rate considering the redundant configuration.

** Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-10 FAILURE RATES FOR DATA LINK LRU'S (FUNCTION D)					
LRU	Part Number	Observed Failure Rate	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
TDDL Antenna	464339	337.84*	1.8	10.00	33.8:1
TDDL Receiver	464667	8,230.45	42.8	8,676.04	-
TDDL Converter Receiver Control	464019	2,618.78	13.7	1,127.89	2.3:1
TDDL Digital-Digital Converter	464220	2,618.78	13.7	21,509.59	-
Rack	464811	77.96*	0.4	6.00	13.0:1
Rack	464074	4,489.34	23.4	161.18	27.9:1
Computer Mode Annunciator	464034	467.73*	2.4	27.55	17.0:1
Auto Navigation Selector Control	464955	374.11	1.8	17.63	21.2:1
Total		19,214.99		31,535.88	

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-11
FAILURE RATES FOR COMPUTER LRU'S (FUNCTION C)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
AC Inputs SDC	464023	3,367.00	1,314.96		
Analog-Digital Signal Comparator	464050	3,741.11	1,626.98		
Digital Output Phase Change Relay Assembly	464064	5,237.56	7,143.42		
Digital Computer Interconnection Box	464318	1,117.32*	715.47		
Analog Signal Sampling Electronic Switch	464051	6,734.01	4,994.07		
Analog Outputs SDC	464123	16,460.91	9,972.57		
Input-Output SDC	464255	18,705.57	18,184.11		
Digital SDC	464323	4,863.45	8,412.51		
Control Electronics Digitizer Computer	464446	13,468.01	16,584.21		
Arithmetic Electronic Digitizer Computer	464146	20,950.24	22,814.48		
Shift Register Digitizer Memory	464157	2,992.89	5,027.19		
Clock Pulse Generator	464489	1,122.33	723.76		
Read-Write Memory Amplifier Assembly	464457	10,475.12	8,717.26		
Data Storage Magnetic Drum	464057	5,237.56	891.13		
Read Memory Diode Gate Assembly	464657	2,618.78	7,365.56		
Electronic Equipment Rack, Right Hand (RH) Forward	464273	3,367.00	248.50	N/C	N/C
Total		120,458.86	114,736.18	120,458.86	114,736.18

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-12
FAILURE RATES FOR MA-1 POWER LRU'S (FUNCTION P)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate*	Predicted Failure Rate	Observed Failure Rate*	Predicted Failure Rate
System Power Control	464905	3,741.11	440.99	13,503.20	738.59
Undervoltage-Overvoltage Relay Assembly	464062	1,496.45	2,545.41		
+28V and -140V DC Voltage Regulator Assembly	464692	2,992.89	1,052.08		
Interconnection Box No. 1	464018	4,115.23	1,499.04		
Interconnection Box No. 2	464118	2,688.17*	1,331.55		
AC-DC Generator	31056	4,306.63**	145.08		
Power Transfer Relay Assembly	464162	2,992.89	3,298.12		
-250V DC Power Supply	464192	2,618.78	2,078.04		
400 cps and 1600 cps Voltage Regulator Assembly	464892	6,734.01	2,291.10		
100 Millihenry Reactor	464135	298.60*	2.97		
40 Millihenry Reactor	464035	181.92*	10.00		
DC Slip Ring Generator	464689	2,618.78	100.00		
+300V and -150V DC Voltage Regulator Assembly	464792	2,244.67	1,200.22		
+300V DC Power Filter	464092	1,496.45	521.28		
+150V DC Power Filter	464991	748.22	821.13		
+300V DC Power Filter	464591	5,237.56	997.34		
+150V DC Power Filter	464891	1,122.33	551.21		
-140V DC Power Filter	464791	2,992.89	895.77		
+100V and -140V DC Voltage Regulator	464292	4,863.45	764.39		
-155/55, 1600 cps, +300 Reference Voltage Regulator	464491	9,352.79	447.28		
+50V, -50V and -15V Transistor Power Supply	464326	2,992.89	945.35	1,761.29	N/C
Computer Z1, +50V DC Reference	464489	1,122.33	723.76		
Total		66,959.04	22,662.11	75,489.53	22,959.71

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

** Failure rate from minutes of the 11 September 1964 TAG meeting.

TABLE 3-13

FAILURE RATES FOR IFF LRU'S (FUNCTION I)

LRU	Part Number	Observed Failure Rate	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
IFF Antenna	2247	-	-	110.00	-
Radio Receiver-Transmitter	464265	16,086.79	67.4	4,648.85	3.5:1
Transponder Coder-Decoder	464028	4,489.34	18.8	3,498.79	1.3:1
Identification Radar Set Control	464555	2,244.67	9.4	106.43	21.1:1
Coder-Decoder Control	464655	748.22	3.2	24.82	30.1:1
Rack	464502	77.96*	0.3	10.00	7.8:1
Rack	464402	207.90*	0.9	10.00	20.8:1
Total		23,854.88		8,408.89	

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-14

FAILURE RATES FOR SEARCH RADAR LRU'S (FUNCTION SR)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
Master Synchronizer	464003	2,992.89	2,684.59		
Radar Transmitter-Receiver	464065	19,453.80	18,281.89	16,438.68	12,345.76
Directional Coupler	464084	1,496.45	133.65	1,761.29	N/C
Waveguide	464016	374.11	505.00	**	254.52
Waveguide	464216	374.11	504.22	587.10	254.52
Antenna	464017	11,971.57	7,276.95		
Dehydrator	464097	7,518.80*	-		
Rack	464774	207.90*	-		
Compressor	464045	4,863.45	380.50		
Valve	464107	4,115.23	104.30		
Mode Selection Radar Set Control	464305	374.11	326.44	318.02	922.72
Radar Set Control	464855	3,367.00	2,091.29	2,544.12	1,743.00
Amplifier Computer	464241	10,101.01	5,885.11		
Scan Generator	464663	6,734.01	7,078.24		
Antenna Servo Amplifier	464206	5,237.56	2,802.76		
Elevation Drive Amplifier	464506	7,482.23	2,209.44		
Azimuth Drive Amplifier	464106	4,489.34	1,931.33		
1600 cps Filter	464425	374.11	12.31		
Electronic Equipment Rack, Left Hand (LH) Forward	464073	5,985.78	427.51	**	N/C
Rack	464173	441.70*	-	**	N/C
Cooling Hat	464190	374.11	-		
Intermediate Frequency (IF) Amplifier	464295	7,108.12	1,542.37	26,419.30	1,546.55
Video Amplifier	464095	9,352.79	3,173.42		
Clutter Gates	464082	2,244.67	3,058.87	2,348.38	3,051.60
Sweep Generator-Amplifier	464195	8,230.45	3,674.90		
Search and Attack Flight Indicator	464080	25,813.69	3,943.67		
Rack	464002	374.11	-		
Cathode-Ray Tube (CRT) Light Filter	464025	1,013.17*	-		
CRT Visor	464125	748.22	-		
Indicator Sweep Generator	464389	3,367.00	3,436.08		
TOTAL		156,581.49	71,464.84		

*Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

**No failures reported, therefore the Pre-Group II failure rate was used again.

TABLE 3-14 (Continued)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
New Units Added During Group II Modification					
PA/RT Power Supply	464026	N/A	N/A	587.10	1,842.35
4 Port Circulator	464432	N/A	N/A	Est. 406.86	220.00
Waveguide Directional Coupler	464484	N/A	N/A	Est. 406.86	110.00
Waveguide Assembly Radar	464516	N/A	N/A	Est. 406.86	394.00
Computer Programmer	464541	N/A	N/A	2,935.48	3,755.04
AFC High Voltage Power Supply	464641	N/A	N/A	29,354.78	6,016.17
Low Voltage Power Supply	464741	N/A	N/A	1,761.29	1,447.25
Hydraulic Drive Unit	464841	N/A	N/A	4,109.67	3,708.94
Total		156,581.49	71,464.84	212,549.02	82,767.18

TABLE 3-15
FAILURE FOR TRACK RADAR* LRU'S (FUNCTION TR)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
Total from Table 3-11	-	156,581.49	71,464.84	212,549.02	82,767.18
Hand Control	464083	8,978.68	1,818.13	6,042.30	N/C
Antenna Tracking Amplifier	464141	6,734.01	3,160.31		
Automatic Gain Control (AGC) and Angle Track Converter	464020	22,446.69	4,463.09		
Torque Generator-Amplifier	464041	2,244.67	1,955.29		
Radar Relay Switch Assembly	464063	1,496.45	3,602.12	1,174.19	3,952.57
Attack Display Amplifier	464395	4,489.34	5,236.41		
Attack Display SDC	464223	2,992.89	3,067.66		
Time-Sharing Electronic SDC	464523	10,475.12	6,388.78		
HIG-4 Rate Gyro	74148	753.58**	490.00		
HIG-4 Rate Gyro	7414A	259.80**	490.00		
Range Track Synchronizer	464103	19,827.91	3,674.32		
Accelerometer	464061	1,122.33	637.72		
Steering Signal Amplifier	464341	4,115.23	3,144.92		
Steering Signal Computer	464346	8,230.45	4,303.04	5,283.86	4,321.39
Total		250,748.64	113,896.63	300,510.94	125,567.77

* In addition to the LRU's listed above, Track Radar also includes those LRU's listed for Search Radar (Table 3-11).

** Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-16
FAILURE RATES FOR INFRARED LRU'S (FUNCTION IR)

LRU	Part Number	Pre-Group II Observed Failure Rate	Pre-Group II Predicted Failure Rate	Post-Group II Observed Failure Rate	Post-Group II Predicted Failure Rate
Nitrogen Tank	464099	9,726.90	159.11		
Rack	464902	207.90*	10.00		
Infrared Receiver	464767	4,115.23	2,096.97		
Rack	464802	77.96*	0.83		
Hose	464399	-	-		
Special Cable	464499	2,992.89	-		
IR SDC	464040	6,359.90	5,668.67		
Passive Detector Synchro Signal Amplifier	464441	8,604.56	3,918.92		
IR Relay Switch Assembly	464663	6,734.01	7,078.24		
Indicator Video	464195	8,230.45	3,674.90		
Indicator	464080	25,813.69	3,943.67		
Audio and ADF ECA	464606	3,367.00	4,946.78		
Headset and Personal Leads	96100	285.71*	-		
Hand Control	464083	8,978.68	1,818.13	6,042.30	N/C
Mode Operations Set Control	464855	3,367.00	2,091.29	2,544.12	1,743.00
Antenna Control Amplifier	464241	10,101.01	5,885.11		
Attack Display Amplifier Assembly	464395	4,489.34	5,236.41		
Attack Display SDC	464223	2,992.89	3,067.66		
Steering Signal ECA	464341	4,115.23	3,144.92		
Time Sharing SDC	464523	10,475.12	6,388.78		
Steering Signal Computer	464346	8,230.45	4,303.04	5,283.86	4,321.39
Total		129,265.92	63,433.43	122,560.07	63,103.49

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-17
FAILURE RATES FOR ARMAMENT LRU'S (FUNCTION A)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
Hand Control Flight Stick	464083	8,978.68	1,818.13	6,042.30	N/C
Armament Self-Test Panel	464596	748.22	274.75		
Armament Test Relay Assembly	464446	13,468.01	16,584.21		
Parameter-Setting Relay Assembly	464364	1,122.33	5,346.17		
Launcher	464054	748.22	1,000.40		
Intervalometer	299	779.42*	-		
Mode-Select Relay Assembly	464464	1,870.56	4,961.93		
Armament Control Relay Assembly	464264	3,367.00	6,844.84		
Transmitter-Tuning ECA	464866	5,611.67	2,448.61	7,045.15	3,505.01
Missile Automatic Flight Control (AFC) Channel Selector	464043	2,992.89	3,427.59		
Missile Antenna Test ECA	464366	748.22	3,089.09		
Missile Antenna ECA	464266	748.22	2,409.97		
Gyro Power Control Panel	464008	748.22	712.33		
Armament Control Power Supply	464087	2,618.78	1,793.84		
Armament Control Relay Box (ACRB)	RY437A	545.85*	-		
Air Control Timer (ACT)	T228A	25.99*	-		
Armament Control Panel (ACP)	8-62221	1,428.57*	-		
Special Weapons Rack (75311)	8-57200	6,410.26*	-		
Total		52,961.11	50,711.86	51,458.21	51,768.26

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-18

FAILURE RATES FOR AUTOMATIC DIRECTION FINDER LRU'S F (FUNCTION ADF)

LRU	Part Number	Observed Failure Rate	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
UHF Receiver, or	464167	50,505.05	*	11,036.96	4.6:1
TDDL Receiver	464667	8,230.45	*	8,676.04	-
ADF Antenna	464117	374.11	1.1	870.73	-
Audio and ADF ECA	464606	3,367.00	10.2	4,946.78	-
Rack	464074	4,489.34	13.5	161.18	27.9:1
Tactical Display HSI	464181	13,468.01	40.1	19,229.66	-
Tactical Display Converter	464920	7,856.34	23.6	5,716.02	1.3:1
Rack	464602	227.40**	0.7	10.00	22.7:1
Rack	464102	2,618.78	7.8	-	-
HSI Indicator	522-2411	748.22	2.2	5,363.83	-
HSI Amplifier	522-1394	250.13	0.8	433.34	-
Total		92,134.83		47,768.50	

* These LRU's are not included because they are required in the following phase in each instance.

** Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

TABLE 3-19

FAILURE RATES FOR INSTRUMENT LANDING SYSTEM LRU'S (FUNCTION L)

LRU	Part Number	Observed Failure Rate	Percent of Total Failure Rate	Predicted Failure Rate	Possible Improvement Ratio
Instrument Landing System (ILS) Receiver Control	464755	623.83	1.23	10.00	62.38:1
Glide Slope Marker Beacon Receiver	464267	14,216.24	28.03	3,691.34	3.85:1
Localizer Receiver	464367	13,468.01	26.55	3,606.45	3.73:1
Amplifier Audio and ADF	464606	3,367.00	6.64	4,946.78	-
Flight Director SDC	464720	3,367.00	6.64	2,670.28	1.26:1
Rack	464511	25.99*	0.05	-	-
Rack	464074	4,489.34	8.85	161.18	27.85:1
Glide Slope Antenna	37P4	597.73*	1.19	-	-
Localizer Antenna	8-36217	259.80*	0.51	8.92	29.13:1
Altitude Direction Indicator	131314-01	10,309.28**	20.32	1,803.97	5.71:1
Total		50,724.22		16,898.92	

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

** Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months) and modified to 80% because of use in only 80% of aircraft that have a vertical configuration.

TABLE 3-20

FAILURE RATES FOR FLIGHT CONTROL AND MEASUREMENT LRU'S (FUNCTION F)

LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
Stable Element	464289	4,489.34	4,464.28		
Rack	464474	129.94*	-		
Roll and Pitch ECA	464109	2,992.89	661.17		
Azimuth ECA	464309	4,489.34	2,336.50		
Junction Box, Latitude Control	464409	2,618.78	3,956.20		
System Power Control	464905	3,741.11	440.99	13,503.20	738.59
Demodulator Channel	464209	2,244.67	979.98		
Integrator ECA	464009	3,367.00	6,481.60		
Rack	464374	1,870.56	7.28		
Static Pressure and Angle-of-Attack Data Compensator	464721	2,111.49**	6,666.00		
Rack	464573	441.70*	-		
Air Data Computer	464646	4,863.45	18,602.63		
Rack	464773	25.99*	-		
Air Data Signal Data Converter	464420	2,244.67	19,177.83		
Rack	464673	181.92*	-		
Altitude Rate SDC	464320	1,493.43**	4,617.70		
Rack	464611	64.97*	-		
Bearing Select Converter Control	464463	1,039.07**	560.01		
Roll and Pitch Rate Gyro	464127	3,741.11	3,542.84		
Control Surface Command Amplifier Computer	464121	7,482.23	2,375.30		
Rack	464873	1,496.45	8.31		
Automatic Flight Control System (AFCS) Flight Mode Control	464163	1,122.33	1,035.77		
Tactical Display HSI	464181	13,468.01	19,229.66		
Rack	464102	2,618.78	-		
Tactical Display Converter	464920	7,856.34	5,716.02		
Rack	464602	227.40*	10.00		
Cockpit Display No. 1 SDC	464520	2,992.89	12,413.26		
Cockpit Display No. 2 SDC	464620	2,244.67	7,903.22		

* Failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months).

** These failure rates were taken from AFLC D056B-2 of 18 November 1964 (6 months) and modified to 80% because of use in only 80% of aircraft that have a vertical configuration.

TABLE 3-20 (Continued)					
LRU	Part Number	Pre-Group II		Post-Group II	
		Observed Failure Rate	Predicted Failure Rate	Observed Failure Rate	Predicted Failure Rate
Aerodynamic Amplifier Computer	464021	1,122.33	1,726.20		
AFCS Normal Aircraft Accelerometer	464161	748.22	281.92		
Navigation and Landing Approach Amplifier Computer	464221	4,115.23	4,373.85		
Communication and Navigational Subsystem Test Set	464396	4,863.45	4,144.55		
Steering Signal Converter Amplifier Computer	464421	3,367.00	6,701.79		
Automatic Attack Amplifier Converter	464621	7,856.34	7,438.21		
Angle-of-Attack Transmitter	2562A-2	1,122.33**	508.96		
Temperature Probe	3225-1A	339.90*	-		
Damper Amplifier	1131-39101	29,411.76*	28,833.31		
Turn-Rate Transmitter	11671G1	4,255.32*	24,778.96		
Pitch G Limiter	8-61100-003	374.11*	9,018.17		
Linear Accelerometer	24522K	1,377.41*	280.00		
Magnetic Azimuth Detector	DT173/AJN	363.77**	-		
Compass Adaptor	131316-01	3,240.44**	2,383.17		
Switching Rate Gyro	MC-1	255.89**	490.00		
Power Supply Amplifier	131313-01	4,098.36**	1,553.15		
Compass Controller	131312-01	1,432.66**	907.49		
Displacement Gyro	129370-01	13,698.63**	4,425.24		
Linear Accelerometer Transmitter	TRU-3A	767.46**	153.38		
Vertical Speed and Altitude Amplifier	15461-1-A1	3,533.57**	1,470.35		
Vertical Speed and Altitude Indicator	18001-2A-5	16,393.44**	29,669.87		
Rate Gyro Transmitter	131311-01	2,915.45**	1,153.73		
Altitude Director Indicator	131314-01	10,309.28**	1,803.97		
Mach Safe Speed Airspeed Amplifier	154621	2,506.27**	1,261.46		
Mach Safe Speed Airspeed Indicator	18000-1A-1	8,333.33**	23,308.23		
Aircraft Flight Director Computer	CPU-4/A	124.69**	2,181.37		
Horizontal Situation Indicator	522-2411	748.22	5,363.83		
HSI Amplifier	522-1394	250.13	433.34		
Attitude Memory Amplifier Computer	464321	4,340.00	3,920.00		
Total		213,925.52	289,751.05	223,689.61	290,048.65

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3.4 Determination of Reliability

In chapter 4 of the original F-106 model report,* the following topics were discussed:

- The reliability of each phase of each of the three standard missions, i.e., the probability that each phase can be successfully completed, given that the equipment operated correctly at the beginning of the mission.
- The impact of each of the 13 functions on the reliability of Mission A, i.e., the percentage of mission reliability improvement that can be achieved by halving the failure rate of each function, in turn, while keeping the failure rates of the other functions constant.
- The improvement in Mission A reliability that could be expected if the most unreliable LRUs in each function were improved by the ratio indicated for the predicted failure rates.

These same general areas were considered during the preparation of this report. The comparison of the mission reliability profiles (Tables 3-21, 3-22, 3-23) show very little change in reliability due to the group II modification. Therefore, very little could be gained by the reassessment of items two and three. For this reason, this discussion is limited to the assessment of the differences in the Pre- and Post-Group II reliability profiles.

The original model report pointed out that the probabilities for mission and phase success presented were apparent probabilities. The actual probabilities of mission success should be greater than the apparent probability because of the following factors:

- The clustering effect at the function and system levels
- The possibility of operating with less than full capability
- The possibility that an LRU part might fail, but the function could be successful because that part was not critical

3.4.1 Reliability Profile for Mission A

Table 3-21 compares the Pre-Group II probabilities taken from the original model report and the Post-Group II probabilities. The differences shown here are not considered significant, since a number of variables other than the equipment modification could account for them. The differences result partly from differences in the operational requirements of the bases used as data sources for the two programs.**

* Analysis of the Reliability Model for the MA-1 AWCIS on the F-106A Aircraft, Contract AF09(603)-48024, ARINC Research Publication 329-01-1-491, 1 March 1965.

**Dover and Selfridge AFBs are operational Air Defense bases, while Tyndall AFB is primarily committed to transition training.

3.4.2 Reliability Profile for Mission B

The probabilities of successful phase completion are compared in Table 3-22. Here, the model differs from Mission A in that the phase times are shorter and the total mission time is shorter.

The differences shown here can be attributed to the differences in the data sources; they do not indicate a significant difference in the reliability of the two equipment configurations.

3.4.3 Reliability Profile for Mission C

The probabilities of successfully completing each phase and all the phases in Mission C are listed in Table 3-23. The low probability of mission success for both configurations can be attributed to the comparatively long mission time involved, and to the constraint that no maintenance can be accomplished during intermediate landings. It can also be attributed to the fact that no degree of reduced capability was considered in these calculations; i.e., either the system operated at full capability at each point in time, or else the system failed.

Here, again, the small difference in the reliability of the Pre- and Post-Group II configurations does not indicate a significant difference in equipments.

3.4.4 Reliability Impact of the Function

Section 4.4 of the original model report presented discussions of potential function improvement and the impact of such improvements on the mission.

The material presented here is concerned largely with the contribution of unit unreliability to a function. The reasons for using this approach (rather than that of the original plan) are the following:

- Although the general approach used in the original analysis could be used "as is", if it should be desirable to update Tables 4-4 and 4-5 of the original model report, it appears that little could be gained by performing this exercise because of the forthcoming modification program.*
- The Group II modification program caused no change at all in many functions (U, T, L, ADF, I, and D) and created only small changes in others (F, C, and A). Functions whose failure rates have undergone the greatest change because of the modification program have little effect on the mission-reliability values.

3.4.4.1 Function F (Flight Control and Measurement)

The only unit within function F to be modified during the Group II program is the System Power Control Unit (P/N 464905). Both the pre- and post-modification predicted failure rates (Table 3-20) indicate a low-complexity unit.

* Changes to the TACAN, Computer, and UHF equipment.

TABLE 3-21

MISSION A RELIABILITY PROFILE

Phase Number	Phase	Cumulative Time (Minutes)	Pre-Group II Probability of Success	Post-Group II Probability of Success
1	Climb	11	0.92581233	
2	Vector	26	0.71110353	
3	Offset	26	0.71110353	
4	Acquire	29	0.66597171	
5	Track	31	0.64117352	0.62197155
6	Launch	31	0.64117352	0.62197155
7	Pullout	32	0.64117352	0.62197155
8	Vector	46	0.52302640	
9	Offset	46	0.52302640	
10	Acquire	49	0.49492620	
11	Track	51	0.47917021	0.45584903
12	Launch	51	0.47917021	0.45584903
13	Pullout	52	0.47917021	0.45584903
14	Return	69	0.43738146	
15	Land	75	0.39139574	0.37140336

TABLE 3-22

MISSION B RELIABILITY PROFILE

Phase Number	Phase	Cumulative Time (Minutes)	Pre-Group II Probability of Success	Post-Group II Probability of Success
1	Climb	4	0.97236838	
2	Vector	19	0.77946580	
3	Offset	19	0.77946580	
4	Acquire	22	0.73481781	
5	Track	23	0.71826223	0.70185316
6	Launch	23	0.71826223	0.70185316
7	Pullout	24	0.71826223	0.70185316
8	Vector	37	0.59540550	
9	Offset	37	0.59540550	
10	Acquire	40	0.56394685	
11	Track	41	0.55264452	0.53091975
12	Launch	41	0.55264452	0.53091975
13	Pullout	42	0.55264452	0.53091975
14	Return	59	0.50464328	
15	Land	65	0.45532100	0.43631359

TABLE 3-23

MISSION C RELIABILITY PROFILE

Phase Number	Phase	Cumulative Time (Minutes)	Pre-Group II Probability of Success	Post-Group II Probability of Success
1	Climb	10	0.93232622	
2	Loiter	54	0.65084237	
3	Return	72	0.59396107	
4	Land	79	0.50081302	0.4948175
5	Climb	90	0.46643225	
6	Vector	104	0.25570040	
7	Acquire	107	0.22229724	
8	Track	108	0.20831394	0.18785840
9	Launch	108	0.20831394	0.18785840
10	Pullout	109	0.20831394	0.18785840
11	Vector	122	0.17268244	
12	Acquire	125	0.16338739	
13	Track	126	0.16028069	0.14210626
14	Launch	126	0.16028069	0.14210626
15	Pullout	127	0.16028069	0.14210626
16	Return	143	0.14703964	
17	Land	150	0.12437449	0.10987635
18	Climb	161	0.08670410	
19	Vector	175	0.08396335	
20	Acquire	178	0.081957998	
21	Track	179	0.074078776	0.062473412
22	Launch	179	0.074078776	0.062473412
23	Pullout	180	0.074078776	0.062473412
24	Vector	193	0.061407804	
25	Acquire	196	0.058102390	
26	Track	197	0.056997614	0.047258280
27	Launch	197	0.056997614	0.047258280
28	Pullout	198	0.056997614	0.047258280
29	Return	214	0.052287890	
30	Land	221	0.042033101	0.034726108

However, a comparison of these two values shows an increase in unit complexity of approximately 67 percent. When this 67-percent increase in the predicted failure rate is compared with a 360-percent increase in the observed failure rate, it is seen that this unit is a candidate for a detailed engineering investigation toward correction of this situation.

It is necessary to consider the impact that improvement of this unit might have on function F and function P (MA-1 Power) before the total gain can be estimated.

3.4.4.2 Function TR (Track Radar)

The TR function is made up of the SR (Search Radar) units plus the additional units needed to perform the track operation. For the purpose of this discussion, only the "additional" units will be included. Units common to both functions are discussed below.

The units within function TR affected by the Group II Program are the Hand Control (P/N 464083), the Radar Relay Switch Assembly (P/N 464063), and the Steering Signal Computer (P/N 464346).

The predicted failure rates (Table 3-15) for two of the three units (P/N's 464063 and 464346) show an increase following modification, and the third unit (P/N 464083) shows no change at all. The observed failure rates (Table 3-12) have decreased for all three units. Table 3-15 provides the comparison of the two equipment configurations and the base line for evaluation of future changes. The third area of interest, units showing high improvement potential, has been eliminated since the units are performing as well as, or better than, expected on the basis of the predictions.

3.4.4.3 Function SR (Search Radar)

The changes to the equipment during the Group II program were largely concentrated within the SR function units.* Ten of the 30 SR function units were modified to some extent. Three of the units (P/N's 464084, 464073, and 464173) showed no change in predicted values due to modifications. Of these units, only the P/N 464084 unit failed during the Tyndall AFB data-acquisition program. For the two units exhibiting no failures during this program, the Pre-Group II failure rates were used** in the current model exercise. The slight increase in the failure rate of the P/N 464084 unit does not represent a change that is considered significant to the function or to the system. However, it should be noted that the observed failure rate for this unit is still higher than should be expected on the basis of the predicted values.

* These units are also used in the TR function.

**The "old" values were used in the revised model for these units to prevent introducing any unwanted bias, as would be possible if "new" values were calculated on the basis of a new sample size and test time.

One additional modified unit (P/N 464305) showed a small increase in failure rate following the modification. This was expected since the predicted failure rate indicated an increase in unit complexity and failure rate. Here, again, the changes shown for this unit will have no measurable impact on either the function of the system.

The P/N 464082 unit exhibits a very small (less than 1 percent) reduction in predicted failure rate and an insignificant ($2\frac{1}{2}$ percent) increase in the observed value. These changes are well within the errors inherent in the method of quantification.

P/N's 464065, 464855, and 464295 of this function (and the TR function) exhibit higher failure rates following the Group II modification program. Of these three units, P/N 464065 and P/N 464855 showed a reduction in predicted failure rates and demonstrated a corresponding improvement in the observed rate changes. The third unit of this group (P/N 464295) has demonstrated the poorest reliability of the modified units. Although there is no significant change in the predicted values, there is a striking difference in the two measured values.* Because of this difference and the fact that this unit contributes a large percentage of the total unit failures of both the SR and TR functions, its maintenance history should be investigated to determine the reason for its poor performance. Then action should be taken to correct the deficiencies that contribute to the reduction in reliability.

The final group of SR-function units consists of the eight units added to the system during the Group II program. For the purpose of this discussion, these new units can be divided into three categories:

(1) Those with very low predicted and observed rates of failure

(2) Those with demonstrated observed failure rates as good as, or better than, expected on the basis of the predicted rates

(3) Those which do not perform as indicated by the predicted failure rates

The first category consists of three units (P/N's 464432, 464484, 464516) with very low predicted failure rates and no observed failures during the data-collection portion of this program. One unit (P/N 464026) had an observed failure rate of approximately 31 percent of the predicted value. The combined failure rates of these four units contribute less than 1.5 percent to the total unit failures within the function and, therefore, present little or no opportunity for improvement. The second category consists of one unit (P/N 464541) that has demonstrated an observed failure rate better than anticipated on the basis of the predicted failure rate, and two units (P/N's 464741 and 464841) for which the observed values closely approximate the predicted values. Thus these three units offer very limited improvement potential.

*Pre-Group II Failure Rate: 7,108.12 failures per million hours.
Post-Group II Failure Rate: 26,419.30 failures per million hours.

The remaining category consists of only the P/N 464641 unit. This unit alone accounts for more than 13.5 percent of all SR-function unit failures and more than 9.5 percent of the total TR-function unit failures. While ranking highest in observed failure rate for both functions on the basis of the predicted values, it ranks fourth in the SR function and fifth in the TR function. Thus this unit becomes a prime candidate for engineering investigation directed at improving reliability.

3.4.4.4 Function IR (Infrared)

The three units related to the TR function are also applicable to functions discussed earlier in this report. The Hand Control, P/N 464083, and the Steering Signal Computer, P/N 464364, have already been discussed, as has the Mode Operations Set Control, P/N 464855. No further discussion of the units is necessary.

3.4.4.5 Function C (Computer)

The one unit associated with the "C" function that was part of the Group II modification program was the equipment rack, P/N 464273. The modification to this unit produced no change to the predicted failure value. Since no electrical changes were made during the Group II modification program, the earlier observed failures were re-used in the revised model.

3.4.4.6 Function U (Command UHF)

The Group II program did not include modification to the units of function U. Therefore, these units appear in this report exactly as in the original document.

Function U units are to be replaced in the near future, thus precluding any requirement to analyze the improvement potential of this equipment.

3.4.4.7 Function P (MA-1 Power)

Two units within function P were modified during the Group II program: the Transistor Power Supply, P/N 464326, and the System Power Control, P/N 464905. The first of these (P/N 464326) showed no change in the predicted value as a result of the modification and showed an improvement in reliability as reflected in a reduction in the Post-Group II observed failure rate. The second unit, P/N 464905, was included in the discussion of the F function since it is part of that function. The only additional comment is that the total impact of any improvement to this unit must be based on its being used in more than one application.

3.4.4.8 Function T (TACAN)

The equipment associated with function T was not modified during the Group II program. In addition, this subsystem is to be replaced in the near future. For the purpose of this model and assessment, the original failure-rate values were re-used in the current effort.

3.4.4.9 Function L (Instrument Landing System)

The original failure-rate values for function L were re-used in the current effort since the units concerned were unaffected by the modification program.

3.4.4.10 Function ADF (Automatic Direction Finder)

The original failure-rate values for function ADF were re-used in the current effort since the units concerned were unaffected by the modification program.

3.4.4.11 Function A (Armament)

The original failure-rate values for function A were re-used in the current effort since the units concerned were unaffected by the modification program.

3.4.4.12 Function I (Identification Friend or Foe)

The original failure-rate values for function I were re-used in the current effort since the units concerned were unaffected by the modification program.

3.4.4.13 Function D (Data Link)

The original failure-rate values for function were re-used in the current effort since the units concerned were unaffected by the modification program.

3.4.5 A Theoretical Mission Reliability

No attempt is made here to calculate a theoretical percentage of improvement for mission A as was presented in the earlier report. Although important to the initial model exercise, a similar assessment of the total system based in part on potential improvement to the TACAN, communications, and computer subsystems now in use would be of little value because of the present plan to replace these systems entirely.

3.5 Conclusions

In general, comparison of the Pre- and Post-Group II mission profiles shows a small decrease in the probability of mission success following Group II modifications. This decrease could be expected as a result of the increase in system complexity caused by the modifications.

A closer look at the functions and units revealed that most of the observed unit failure rates changed in accordance with the changes in complexity and predicted failure rates. Some LRUs did not react as expected. These show the greatest potential for reliability improvement. They are:

(1) System Power Control, P/N 464905

(2) IF Amplifier, P/N 464295

(3) AFC H.V. Power Supply, P/N 464641

3.6 Recommendations

The maintenance history of P/N 464905 and P/N 464295 should be investigated in detail to determine the cause of the increase in observed failure rate that followed this modification program and to determine the required corrective actions.

The history of P/N 464641 should be investigated to determine the causes of the substantial difference between the measured and predicted failure rates and to provide the necessary corrective actions.

4. REVISION OF SYSTEM QUANTIFICATION

4.1 Introduction

The data presented in the original report were for all MA-1 units in the F-106A aircraft. Changes in configuration of the units that were made too late to be accounted for in Technical Order 1F-106-701, dated 3 February 1964, were not included in the program.

For rapid generation of usable data on which initial planning and direction could be based, the MA-1 system was first defined in terms of the "--06" code book, with only 7400 series codes being used.

The system configuration was reviewed in greater detail upon receipt of basic system Technical Orders (particularly T.O. 1F-106A-2-27-1). This review disclosed that a number of units supported by the instrument maintenance facilities were, in fact, part of the MA-1 system. The system redefinition resulted in the addition of several units to the data-collection program. Rather than delay publication, the report was submitted without the measured reliability values for these units. These values were provided when sufficient maintenance information had been accumulated.*

4.2 Theoretical Reliability Characteristics

Full advantage can be taken of theoretical MTBF figures only when the method of derivation is completely defined and understood. The values presented here, as were those in the original document, are based on a simple part count, assuming no redundant or parallel circuit design. The part failure rates used in both this and the original report represent field and operational failures and thus have a built-in average with respect to stress and operating conditions. These rates provide a good estimate of the performance that can reasonably be expected of any particular unit, assuming that typical engineering practices have been applied at the time of design and construction. The failure rates have been determined largely from studies on airborne weapon systems similar to the MA-1, with operational environment and equipment age taken into account, and are judged to be the most pertinent of available data.

A detailed discussion of part failure rates was given in the original report. Since that discussion applies equally to both the original and current programs, it is included here as Appendix A.

*See Table 1-1, ARINC Research Publication 329-01-1-492, 1 March 1965.

4.3 Observed Reliability Characteristics

Here, again, the original program and the updating effort are necessarily based on similar "ground rules." This section is a discussion of these rules, their similarities, their differences, and the reason for their differences.

4.3.1 Data Collection

The measured reliability values presented in the original report were derived from failure and time data (supplemented AFM 66-1 data) collected by ARINC Research engineers stationed at Selfridge and Dover Air Force Bases. These measured values were based on two months of Selfridge flight operations and four months of Dover flight operations, for a combined total of 2,673 F-106 flying hours.

The measured values for the Post-Group II equipment configuration presented in this updating document are also derived from failure and time data. However, in this case the measured values are based on four months of Tyndall Air Force Base flight operation, for a total of 1,703 F-106 flying hours.

4.3.2 Data Organization

The information presented in the tables of the original report were shown in descending order of complexity, i.e., MA-1 System, Subsystem, Equipment Groups, and Line Replaceable Units. In addition, the tables were organized to present measured reliability values for Dover and Selfridge Air Force Bases separately and combined.

The tabular presentation in this report compares the measured reliability values for the equipment configurations for Pre- and Post-Group II. For simplicity, the Dover-Selfridge combined values are used as the Pre-Group II entries.

4.3.3 Observed Reliability Data

The original report presented the mean time between maintenance actions (MTBMA) and mean time between failures (MTBF) for the MA-1 AWCIS.

The MTBMA values were derived by dividing the number of flight hours by the total maintenance actions initiated against the system, the subsystem, and the LRUs, respectively.

The MTBF values were derived by dividing the number of flight hours by the number of maintenance actions necessary to satisfy complaints against the system, the subsystem, and the LRUs, respectively. MA-1 elements in which no malfunction was found were not included in the MTBF calculations.

In all cases, the system or subsystem was considered to be maintained (MTBMA) or failed (MTBF) only one time during any one maintenance action even though more than one LRU of the system or subsystem was involved.

These same rules were used in the collection and preparation of the revision data. However, the effort was limited to include only those units (and associated subsystems) which were affected by the Group II modification program. Table 4-1 of this report presents a comparison of Pre- and Post-Group II MTBMA's and Pre- and Post-Group II MTBF's for all units affected by the modification program.

4.3.4 Theoretical and Measured MTBF

Theoretical and measured MTBFs were compared in the original report. The original data were tabulated to show values for round- and vertical-instrumented aircraft and combined values.

Similar material is given in this report; however, the tabular presentation compares only those units which were affected by the Group II modification program.

Table 4-2 presents a comparison of the following:

(1) Pre-Group II predicted (or theoretical) MTBF values

(2) Post-Group II predicted (or theoretical) MTBF values

(3) Pre-Group II measured (or observed) MTBF values

(4) Post-Group II measured (or observed) MTBF values

The conditions and assumptions that applied to the acquisition and presentation of the MTBF values were discussed in earlier sections of this report and in the original report and will not be repeated here. The same constraints were imposed in both programs.

4.4 Observed Maintainability Data

In the original report, maintainability data were presented in terms of total downtime and total repair time at the system and subsystem levels, with separate presentations for each category of data from each base. The method of data presentation has been modified for this report in that it is limited to the total MA-1 system downtime and repair time.

4.4.1 MA-1 System Total Downtime

System-total-downtime data (see Table 4-3) indicate the probability of completing maintenance within time t for the Post-Group II equipment configuration. These data encompass elapsed time from landing to correction of all system deficiencies. The number of actions completed at time t_c and the cumulative total of actions completed through time t_c are shown. Figure 4-1 is a graphic presentation of these data and the Pre-Group II data from Dover and Selfridge Air Force Bases.

4.4.2 MA-1 System Repair Time

System-repair time data (see Table 4-3) indicate the probability of completing maintenance within time t for the Post-Group II equipment configuration. These data encompass all time consumed in direct maintenance to correct all system discrepancies, the number of actions completed at time t_c, and the cumulative total of actions completed through time t_c. Figure 4-2 is a graphic presentation of these data and the Pre-Group II data from Dover and Selfridge Air Force Bases.

4.5 Shop Repair Time for Line Replaceable Units

The original report reflected average repair time in man-hours for MA-1 system LRUs for which measured data were available. This same tabular presentation has been modified for this report to show measured data from Dover and Selfridge Air Force Bases as the Pre-Group II values and data from Tyndall as the Post-Group II values.

The data entries are presented here in Table 4-4 in the same way that Pre-Group II data were presented in the original report; i.e., LRUs with less than four maintenance actions were not considered representative. However, the LRUs from the Tyndall data are included in this report to show the observed LRU repair times. For those units with less than four failures, the number of repair actions is shown.

TABLE 4-1
DATA COMPARISON FOR THE RADAR SUBSYSTEM, PRE AND POST-GROUP II IIP MODIFICATION: AT 95 PERCENT CONFIDENCE LEVEL

Part Number	Unit	Measured MTBMA						Measured MTBF					
		Pre-Group II			Post-Group II			Pre-Group II			Post-Group II		
		UCL*	MTBMA	LCL	UCL	MTBMA	LCL	UCL	MTBF	LCL	UCL	MTBF	LCL
	Fire Control												
	Radar Subsystem Group I												
464002	Rack, Indicator Pressure	11045	2673	482				11045	2673	482			
464003	Synchro, Master Timer	270	167	103				650	334	170			
464016	Waveguide Assembly	11045	2673	482				11045	2673	482			
464017	Antenna, Radar	99	72	52				118	83	59			
464020	Converter, Waveform	39	32	23				58	45	35			
464041	Amplifier, Torque Generator	251	157	98				950	445	205			
464045	Compressor, Air	292	178	108				349	206	120			
464063	Relay, Switch Assembly	431	243	136	1048	341	146	1645	668	261	7038	852	237
464065	Receiver, Transmitter Radar	68	51	39	85	56	40	68	51	39	93	61	42
464073	Rack, LH Forward Compartment	219	141	90	414	189	100	270	167	103	774	284	131
464080	Indicator, Flight Command	41	33	27				49	39	31			
464082	Gate Clutter	387	223	128	605	242	118	950	445	205	1563	426	166
464083	Control Manual	118	83	59	97	63	44	165	111	75	280	166	107
464084	Coupler, Directional	1645	668	260	2747	568	195	1645	668	260	2747	568	195
464095	Amplifier, Video	91	67	49				157	107	72			
464096	Meter, Radar Self Test	11045	2673	482				---	---	---			
464103	Synchro, Range Track	42	34	27				66	50	39			
464106	Amplifier, Azimuth Drive	183	121	80									
	Radar Subsystem Group II												
464107	Valve, Auto, Regulator	349	206	120				431	243	136			
464125	Visor, Cathode Ray Tube	2452	891	305				4311	1336	371			
464141	Amplifier, Antenna Track	55	96	70				233	148	94			
464149	Recorder, Photographic	118	83	59				138	95	66			
464150	Comparator, Signal	2452	891	305				11045	2673	482			
464169	Sight, Fixed	349	206	120				349	206	120			
464173	Rack, Atenna, Transmitter Group	11045	2673	482				---	---	---			
464190	Duct, Assembly, R/M Cool	2452	891	305				11045	2673	482			
464195	Amplifier, Sweep Generator	132	92	64				183	121	80			
464196	Relay, Switch Assembly	557	297	156				1215	535	229			
464206	Amplifier, Antenna Servo	138	95	66				318	1191	113			
464216	Waveguide Assembly	11045	2673	482	67324	1703	307	11045	2673	482	67324	1703	307
464223	Converter, Signal Data	270	161	103				650	334	170			
464241	Amplifier, Computer	66	50	39				144	99	68			
464295	Amplifier, IF	113	81	58	49	36	27	219	141	90	50	38	28
464305	Control, Radar Set	1215	535	229	124288	3145	567	11045	2673	482	124289	3145	567
464341	Amplifier, Filter Assembly	165	111	75				431	243	136			
464346	Computer, Steering Signal	106	76	55	152	90	58	183	121	80	414	189	100
464389	Generator, Sweep	207	167	103				557	297	156			
464425	Filter, Band Pass	2452	897	305				11045	2673	482			
464495	Amplifier, Video	473	267	145				1644	668	261			
464506	Amplifier, Elevation Drive	127	89	62				206	134	86			
	Radar Subsystem, Group III												
464026	Power Supply				2747	568	195				67324	1703	307
464432	4-Port Circulator				2747	568	307**						407**
464484	Directional Coupler				2747	568	307**						407**
464516	Waveguide Assembly				2747	568	307**						407**
464541	Computer Programmer				605	243	118				1048	341	146
464641	AFC Power Supply				31	24	19				46	34	26
464741	LV Power Supply				1562	426	166				2747	568	195
464841	Hydraulic Drive				310	155	86				605	243	118
464855	Control, Radar Set	292	178	108	456	242	141	557	297	156	910	393	200
464866	Amplifier, Transmitter Tuning	206	143	86	223	122	73	292	178	108	275	142	81
464523	Converter, Signal Data	79	59	44				138	95	66			
	Non-Radar System Units												
464273	Rack, RH Forward Compartment	431	243	136	2747	568	195	557	297	156	7038	852	237
464326	Power Supply	349	206	120	1562	426	166	650	334	170	119	74	50
464905	Control, System Power	206	134	86	93	61	42	473	267	145	119	74	50

* UCL = Upper confidence limit. LCL = Lower confidence limit.

** Calculated LCLs.

TABLE 4-2

DATA COMPARISON, RADAR SUBSYSTEM PRE-GROUP II PART-GROUP II IIP MODIFICATION

Part Number	Unit	Theoretical MTBF		Measured MTBF at 95-Percent Confidence Limit					
		Pre-Group II IIP	Post-Group II IIP	Pre-Group II IIP			Post-Group II IIP		
				UCL	MTBF	LCL	UCL	MTBF	LCL
	Fire Control								
	Radar Subsystem Group 1								
464002	Rack, Indicator Pressure	NE		11045	2673	482			
464003	Synchro, Master Timer	373.5		650	334	170			
464016	Waveguide Assembly	1980.0		11045	2673	482			
464017	Antenna, Radar	137.4		118	83	59			
464020	Converter, Waveform	242.1		58	45	35			
464041	Amplifier, Torque Generator	511.4		950	445	205			
464045	Compressor, Air	2628.1		349	206	120			
464063	Relay, Switch Assembly	277.6	253.0	1645	668	261	7038	852	237
464065	Receiver, Transmitter Radar	54.7	81.0	68	51	39	93	61	42
464073	Rack, LH Forward, Compartment	2339.1	2339.1	270	167	103	774	284	131
464080	Indicator, Flight Command	253.8		49	39	31			
464082	Gate Clutter	327.8	327.8	950	445	205	1563	426	166
464083	Control Manual	531.0	550.0	165	111	75	280	166	107
464084	Coupler, Directional	7482.2	7482.2	1645	668	260	2747	568	195
464095	Amplifier, Video	315.1		157	107	72			
464096	Meter, Radar Self Test	10134.8		---	---	---			
464103	Synchro, Range Track	272.2		66	50	39			
464106	Amplifier, Azimuth Drive	517.8							
464107	Valve, Automatic, Regulator	9587.7		431	243	136			
464125	Visor, Cathode Ray Tube	NE		4311	1336	371			
464141	Amplifier, Antenna Track	316.4		233	148	94			
464149	Recorder, Photographic	141.9		138	95	66			
464150	Comparator, Signal	707.4		11045	2673	482			
464169	Sight, Fixed	1293.4		349	206	120			
464173	Rack, Atenna Transmitter Group	NE		---	---	---			
464190	Duct, Assembly R/M Cool	NE		11045	2673	482			
464195	Amplifier, Sweep Generator	272.1		183	121	80			
464196	Relay, Switch Assembly	243.9		1215	535	229			
464206	Amplifier, Antenna Servo	356.8		318	1191	113			
464216	Waveguide Assembly	1983.3	3929.0	11045	2673	482	67324	1703	307
464223	Converter, Signal Data	326.0		650	334	170			
464241	Amplifier, Computer	170.0		144	99	68			
464295	Amplifier, IF	648.4	646.6	219	141	90	50	38	28
464305	Control, Radar Set	3062.4	1083.8	11045	2673	482	124289	3145	567
464341	Amplifier, Filter Assembly	318.0		431	243	136			
464346	Computer, Steering Signal	232.4	231.4	183	121	80	414	189	100
464389	Generator, Sweep	291.0		557	297	156			
464425	Filter, Band Pass	81234.8		11045	2673	482			
464495	Amplifier, Video	545.7		1644	668	261			
464506	Amplifier, Elevation Drive	452.6		206	134	86			

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TABLE 4-3

MA-1 POST-GROUP II DOWNTIME AND REPAIR TIME

Calendar Time, t_c (Hours)	Total System Downtime			Total System Repair Time		
	Number of Actions at End of Time t_c	Cumulative Actions	Probability of Completing Actions Within Time t_c	Number of Actions at End of Time t_c	Cumulative Actions	Probability of Completing Actions Within Time t_c
0.00 -- 0.50	0	0	0.000000	3	3	0.004862
0.50 -- 1.00	15	15	0.024311	26	29	0.047002
1.00 -- 1.50	0	15	0.024311	0	29	0.047002
1.50 -- 2.00	55	70	0.113452	81	110	0.178282
2.00 -- 2.50	0	70	0.113452	0	110	0.178282
2.50 -- 3.00	83	153	0.247974	91	201	0.325770
3.00 -- 3.50	23	176	0.285251	0	201	0.325770
3.50 -- 4.00	44	220	0.356564	89	290	0.470016
4.00 -- 4.50	0	220	0.356564	20	310	0.502431
4.50 -- 5.00	81	301	0.487844	48	358	0.580227
5.00 -- 5.50	0	301	0.487844	6	364	0.589951
5.50 -- 6.00	49	350	0.567261	44	408	0.661264
6.00 -- 6.50	12	362	0.586710	0	408	0.661264
6.50 -- 7.00	35	397	0.643436	35	443	0.717990
7.00 -- 7.50	6	403	0.653160	23	466	0.755267
7.50 -- 8.00	26	429	0.695300	5	471	0.763371
8.00 -- 8.50	0	429	0.695300	6	477	0.773096
8.50 -- 9.00	26	455	0.737439	9	486	0.787682
9.00 -- 9.50	0	455	0.737439	4	490	0.794165
9.50 -- 10.00	13	468	0.758509	12	502	0.813614
10.00 -- 11.00	10	478	0.774716	15	517	0.837925
11.00 -- 12.00	14	492	0.797407	21	538	0.871961
12.00 -- 13.00	20	512	0.829822	14	552	0.894652
13.00 -- 14.00	13	525	0.850891	4	556	0.901135
14.00 -- 15.00	9	534	0.865478	9	565	0.915721
15.00 -- 16.00	9	543	0.880065	5	570	0.923825
16.00 -- 17.00	2	545	0.883306	6	576	0.933549
17.00 -- 18.00	7	552	0.894652	1	577	0.935170
18.00 -- 19.00	2	554	0.897893	1	578	0.936791
19.00 -- 20.00	4	558	0.904376	5	583	0.944895
20.00 -- 21.00	0	558	0.904376	4	587	0.951378
21.00 -- 22.00	2	560	0.907618	4	591	0.957861
22.00 -- 23.00	6	566	0.917342	3	594	0.962723
23.00 -- 24.00	5	571	0.925446	1	595	0.964344
24.00 -- 25.00	1	572	0.927066	3	598	0.969206
25.00 -- 26.00	3	575	0.931929	0	598	0.969206
26.00 -- 27.00	1	576	0.933549	2	600	0.972447
27.00 -- 28.00	5	581	0.941653	2	602	0.975689
28.00 -- 29.00	4	585	0.948136	0	602	0.975689
29.00 -- 30.00	2	587	0.951378	0	602	0.975689
30.00 -- 40.00	16	603	0.977310	9	611	0.990276
40.00 -- 50.00	3	606	0.982172	3	614	0.995138
50.00 -- 60.00	3	609	0.987034	2	616	0.998379
60.00 -- 70.00	1	610	0.988655	0	616	0.998379
70.00 -- 80.00	0	610	0.988655	0	616	0.998379
80.00 -- 90.00	1	611	0.990276	0	616	0.998379
90.00 -- 100.00	2	613	0.993517	1	617	1.000000

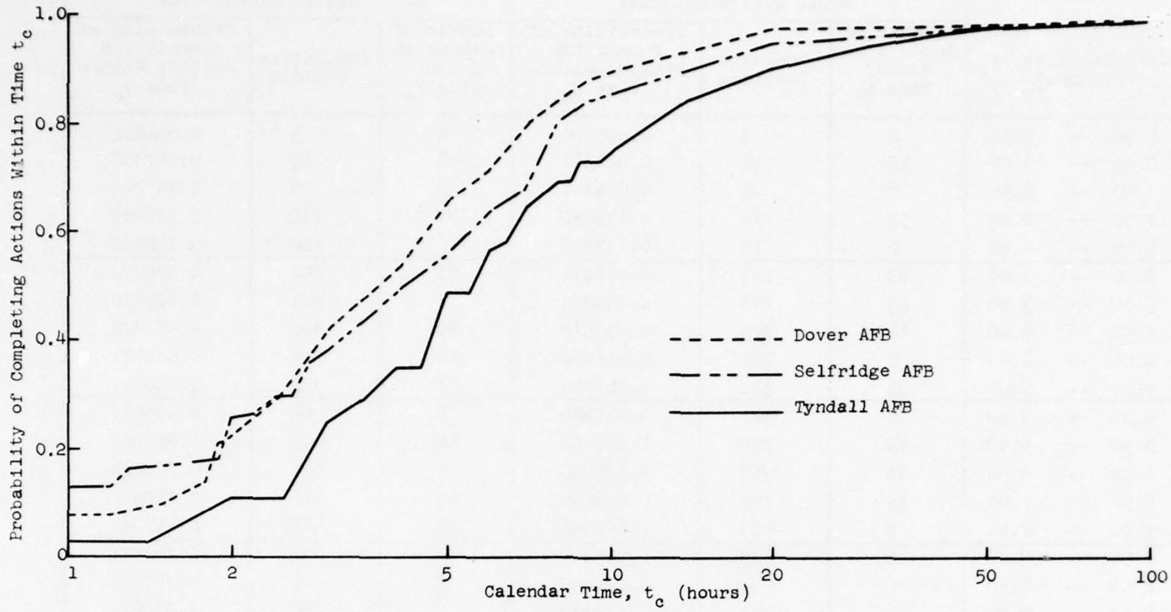


FIGURE 4-1

MA-1 DOWNTIME

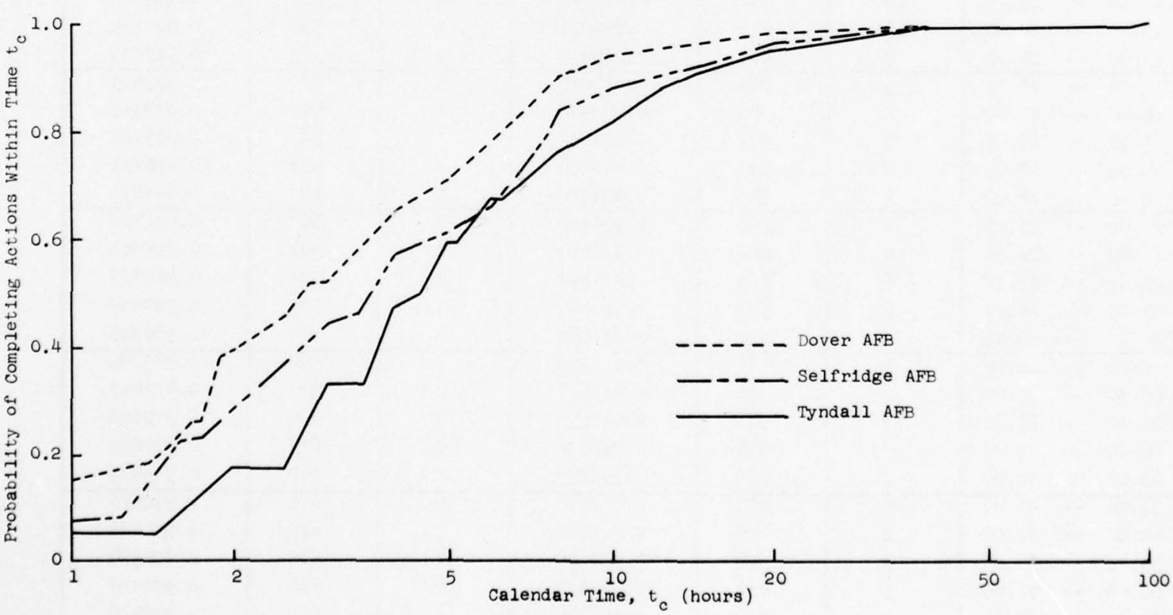


FIGURE 4-2

MA-1 DOWNTIME

TABLE 4-4

ACTIVE REPAIR TIME FOR LINE REPLACEABLE UNITS OF THE MA-1 SYSTEM

Part Number	Unit	Average Man-Hours Per Repair Action Per LRU		
		Pre-Group II		Post-Group II
		Dover	Selfridge	Tyndall
	Fire Control			
	Radar Subsystem Group I			
332D6	Gyro, Vertical	---	---	---
463097	Dehydrator	---	---	---
464002	Rack, Indicator, Pressure	---	---	---
464003	Synchronizer, Master Timer	0.6	2.1	---
464016	Waveguide Assembly	---	---	---
464017	Antenna, Radar	3.2	4.2	---
464020	Converter, Waveform	0.8	1.5	---
464024	Indicator, Pressure	---	---	---
464025	Filter, Light CRT	---	---	---
464041	Amplifier, Torque Generator	0.6	1.8	---
464045	Compressor, Air	2.8	1.2	---
464063	Relay, Switch Assembly	1.6	0.8	2.1
464065	Receiver, Transmitter Radar	6.8	2.7	3.4(3)
464073	Rack, LH Forward Compartment	7.0	3.3	4.0(2)
464080'	Indicator, Flight Command	1.9	3.3	---
464082	Gate, Clutter	0.5	2.4	2.1
464083	Control, Manual	1.1	2.4	2.8
464084	Coupler, Directional	---	---	3.0(1)
464095	Amplifier, Video	0.6	2.4	---
464096	Meter, Radar Self Test	---	---	---
464103	Synchronizer, Range Track	1.1	1.4	---
464106	Amplifier, Azimuth Drive	1.2	1.7	---
	Radar Subsystem Group II			
464107	Valve, Automatic Regulator, Pressure	2.6	1.4	---
464125	Visor, Cathode Ray Tube	---	---	---
464141	Amplifier, Antenna Tracking	0.8	1.3	---
464149	Recorder, Photographic	1.3	2.3	---
464150	Comparator, Signal	---	---	---
464169	Sight, Fixed	---	---	---
464173	Rack, Antenna Transmitter Group	---	---	---
464190	Duct Assembly, Receiver Modulator Cooling	2.1	---	---
464195	Amplifier, Sweep Generator	1.3	---	---

TABLE 4-4 (Continued)

Part Number	Unit	Average Man-Hours Per Repair Action Per LRU		
		Pre-Group II		Post Group II
		Dover	Selfridge	Tyndall
464196	Relay, Switch Assembly	0.8	1.2	---
464206	Amplifier, Antenna Servo	1.5	1.1	---
464216	Waveguide Assembly, Radar	---	---	---
464223	Converter, Signal Data	0.6	1.0	---
464241	Amplifier, Computer	1.4	1.5	---
464295	Amplifier, IF	1.3	1.0	2.2
464305	Control, Radar Set	---	1.8	3.3 (1)
464341	Amplifier, Filter Assembly	1.0	1.6	---
464346	Computer, Steering Signal	0.9	2.1	2.5
464389	Generator, Sweep	1.1	1.3	---
464395	Amplifier, Attack Display	0.5	2.0	---
464425	Filter, Bandpass	---	---	---
464495	Amplifier, Video	0.4	---	---
464506	Amplifier, Elevation Drive	1.7	1.3	---
	Radar Subsystem Group III			
464674	Rack, Dehydrator	---	---	---
464702	Rack, Remote Scope Record	---	---	---
464774	Rack, Dehydrator and Filter	---	---	---
464796	Panel, Self-Test IAWCS	---	---	---
464855	Control, Radar Set	---	1.2	2.5
464866	Amplifier, Transmitter Tuning	0.9	1.2	2.1
464523	Converter, Signal Data	1.0	1.2	---
464026	Power Supply	---	---	1.3 (3)
464432	4-Port Circulator	---	---	1.0 (1)
464484	Directional Coupler	---	---	---
464516	Waveguide Assembly	---	---	---
464541	Computer Programmer	---	---	5.0
464641	AFC Power Supply	---	---	5.0
464741	LV Power Supply	---	---	1.5 (3)
464841	Hydraulic Drive	---	---	2.2
	Non-Radar System Units			
464273	Rack, RH Forward Compartment	---	---	2.1 (1)
464326	Power Supply	---	---	3.0
464905	Control, System Power	---	---	2.1

Note: Number in parentheses indicates number of observed repair actions for units having less than 4 failures.

5. INVESTIGATION OF POWER SUBSYSTEM

5.1 Background

During the earlier F-106 contract activity, ARINC Research published, measured, and predicted MTBF values for units of the F-106 MA-1 system*. Analysis of these values showed that the system could be improved significantly by improving the reliability of certain units in the power subsystem. Several recommendations for unit improvement were made during the continuing program. However, because of the priorities given to the UHF and TACAN systems, the power subsystem received limited attention. More recently, greater attention has been given to the power subsystem since it now appears to be a major contributor to MA-1 unreliability. Modification programs to other portions of the system incorporating units or subsystems with more critical power requirements have contributed to this problem.

Additional factors that affect system performance but are a part of the power-subsystem are changes in power-system loads resulting from modification programs and changes to wiring, shielding, and ground returns. The more recent investigation disclosed situations in which modifications caused the generation of transients, which were being introduced into the power busses.

Analysis of flight-symptom data showed that most malfunctions reported by the operator directly against the power subsystem (ADCR 66-28 Codes: PP-) are normally verified by the maintenance technician and readily corrected. The more common reliability and maintainability problems associated with the power subsystem are well known, and a qualified flight-line technician has no trouble isolating actual failures in this subsystem. However, marginal performance, power-line noise, and other abnormal conditions occurring in the power-distribution busses in the different operational models of the F-106 weapons system cannot be readily identified by the operator as power subsystem problems. This results in an operator complaint that cannot be verified by the maintenance technician.

The operator usually identifies the problem as being related to the subsystem that displayed degraded performance. The radar, computer, and automatic-flight-control subsystems are the most critical to power requirements and are frequently reported as degraded when the problem is actually in the power being supplied to the subsystems. Problems of this type have been found to contribute to the high rate of unit adjustments (e.g., the steering and tracking functions), which in turn can upset the balance of the functional subsystems. They also reduce the

*ARINC Research Publication 329-01-1-492, Quantified Reliability and Maintainability Characteristics of the F-106 AWCIS, 1 March 1965.

percentage of next-flight success. With the incorporation of the more recent modifications such as multi-mode storage display unit, P/N 464080-181, new adjustment problems are being encountered. The new Multi-Mode Storage Tube (MMST) 464080 unit has been found to be extremely critical to the presence of noise in the ±50 Vdc supplied by the P/N 464326 unit.

Earlier investigations were concerned with units 892/992, 491, and 326. However, the overall system effects of marginal unit performance were identified. Design deficiencies, technical-order and procedural inadequacies, and test-equipment and AGE (Aerospace ground equipment) deficiencies were defined. These findings and those of earlier efforts indicated that a more detailed study of the power subsystem was necessary to define its characteristics and deficiencies.

Since most components in the power subsystems were designed approximately ten years ago, the state of the art and the standards for aircraft electrical power have changed substantially. Deficiencies that appear, by present standards, to be design inadequacies, such as deficient components (transistors, diodes, and resistors), are a problem common to most equipment designed in that time period. An additional problem is the location of heat-sensitive parts next to heat-producing comonents.

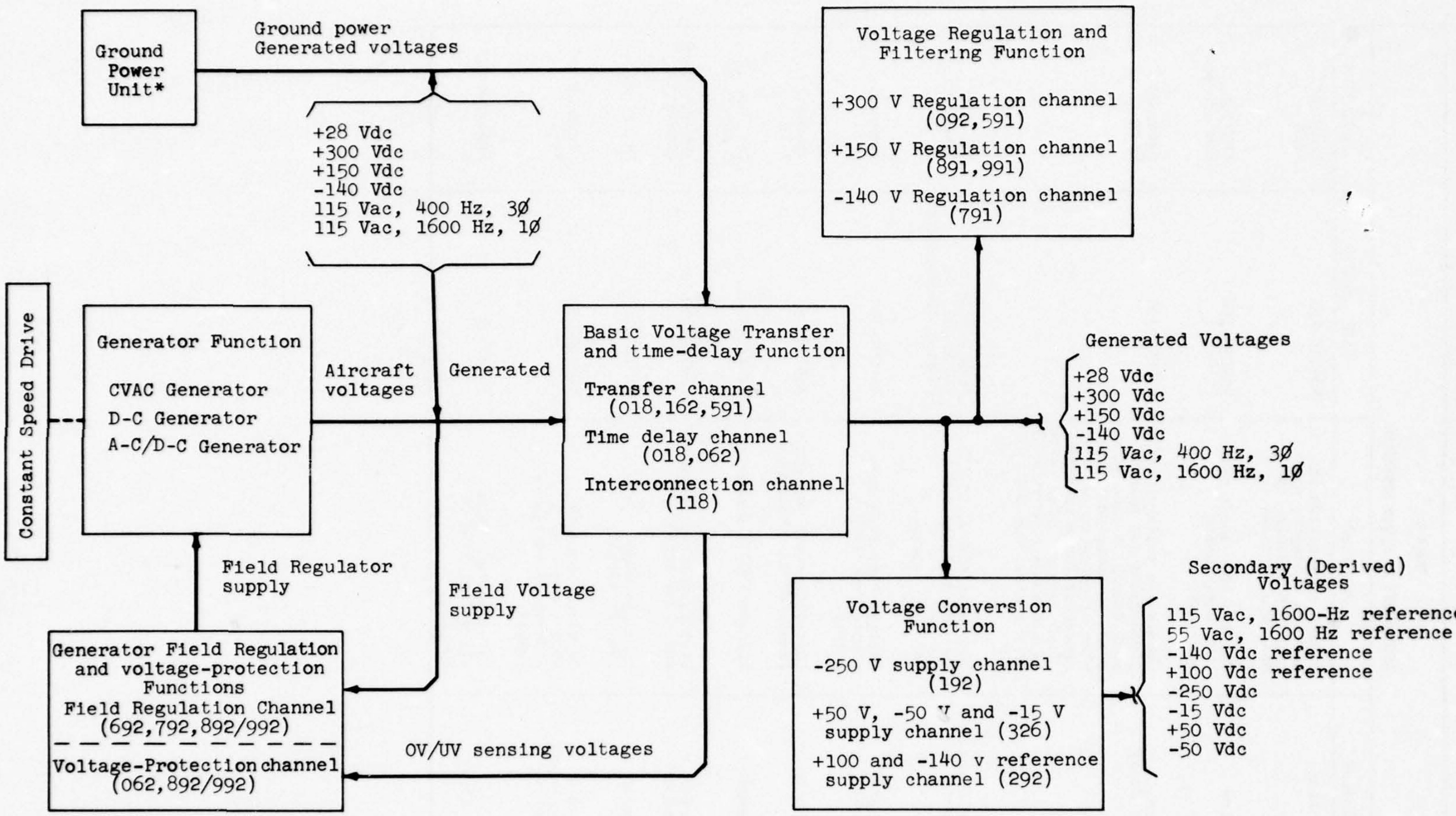
The MA-1 power subsystem is representative of the state of the art for the time of its design. Thus many problems associated with this system are common to most systems of similar age. This study was directed toward better definition of the exact conditions present in the MA-1 power subsystem and the impact of any anomalous conditions on F-106 reliability.

5.2 General Description of the MA-1 Power Subsystem

The F-106 MA-1 power subsystem develops the voltages necessary to operate the MA-1 AWCIS. In addition, the power subsystem performs switching, transfer, time-delay, and over/under-voltage-protection functions, as diagramed in Figure 5-1. The basic power subsystem consists of 21 individual units. Table 5-1 lists the 21 units of power subsystem and the function of each. A more detailed distribution diagram, not including the timing, switching, or over/under-voltage circuitry, is presented in Figure 5-2 to show the high degree of interdependency of the power-subsystem functions.

The aircraft installation of the power-subsystem units is shown in Figure 5-3, with the location of the ARINC Research flight-recorder package. The recorder was installed in the space normally occupied by the P/N 464296 unit for the in-flight recording of the power subsystem's parameters.

In addition to the 21 basic power-subsystem components, there are a number of specialized power supplies in the MA-1 system, including units 464229, 464392, 464489, 464741, and 464746. Although these units are not considered a part of



*Power is supplied from either the ground power unit or the aircraft generators.

FIGURE 5-1

BLOCK DIAGRAM OF POWER SUBSYSTEM

TABLE 5-1

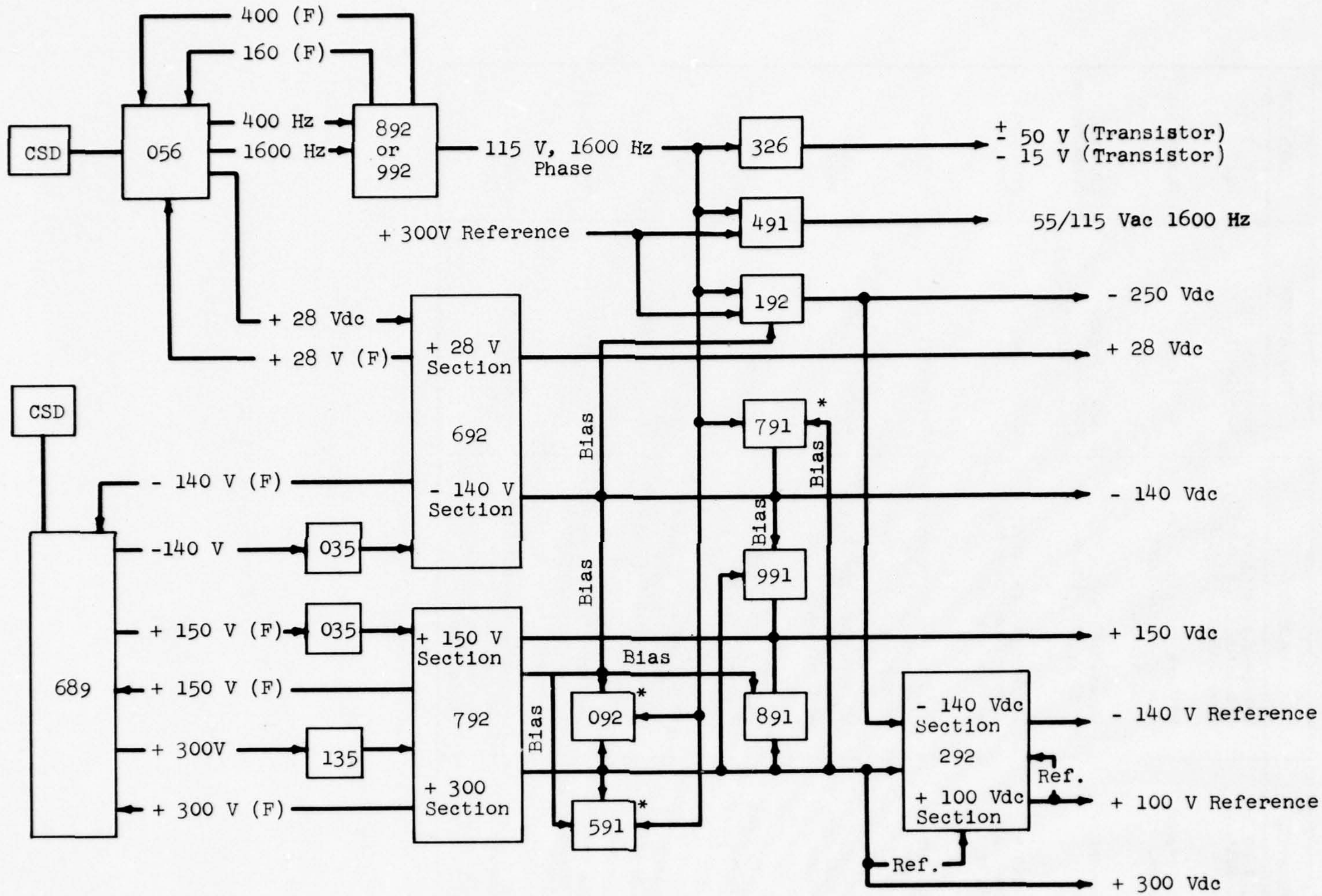
COMPONENTS OF POWER SUBSYSTEM

ITEM	NOMENCLATURE	FUNCTION	PART NUMBER	LOCATION
1	Interconnecting Box No. 1	Delays application of certain voltages; distributes voltages to MA-1 system buses.	464018-153	Armament Rack
2	40-Millihenry Reactor	Filters the -150 v and -140 v generated voltages.	464035-152 (2 Req.)	CSD-Gen. Compartment
3	Undervoltage, Overvoltage Relay Assembly	Senses d-c voltages and disconnects a-c generator fields in case of over- or under-voltage; also disconnects a-c generator field in case of an over or under value in a-c voltage on receipt of a signal from 892 or 992.	465062-151	Armament Rack
4	Alternating-Current/ Direct-Current Generator	Generated +28 V, 115 V, 400-Hz, 3-phase; and 115 V, 1600-Hz, 1-phase.	Jack & Heintz 31056-002 (Hughes 464089-150)	CSD-Gen. Compartment
5	+300 V Direct-Current Power Filter	Filters high frequency ripple from +300 v supply.	464092-150	Armament Rack
6	Interconnecting Box No. 2	Distributes 400-Hz and generated d-c voltages.	464118-153	Armament Rack
7	100-Millihenry Reactor	Filters +300 V supply.	464135-152	CSD-Gen. Compartment
8	Power-Transfer Relay Assembly	Distributes a-c voltage and +28 V supply.	464162-152	AFT-Fuselage (Sta 145)
9	-250 Vdc Power Supply	Develops -250 from 1600 Hz supply.	464192-175	Radar Rack
10	+100 V, -140 V Voltage Regulator, Ref. to +300 V	Develops accurate +100 v and -140 v referenced to +300 v supply.	464292-150	Armament Rack
11	±50 V & - 15 V Transistor Power Supply	Develops ±50 v and -15 v from 1600-Hz supply.	464326-150	Radar Rack

TABLE 5-1 (continued)

COMPONENTS OF POWER SUBSYSTEM

ITEM	NOMENCLATURE	FUNCTION	PART NUMBER	LOCATION
12	115/55 V, 1600 Hz +300 Ref. Voltage Regulator	Develops accurately regulated 115 v and 55 v from 1600-Hz supply.	464491-150 or 464491-175	C.N. & L. Rack
13	+300 Volts Direct Current Power Filter	Filters the high frequency ripple from +300 v supply.	464591-151	Radar Rack
14	Direct Current Slip Ring Generator	Generates +300 v, +150 v, and -140 v.	Jack & Heintz 31055-006 (Hughes 464689-151)	CSD-Gen. Compartment
15	+28 V & -140 V D. C. Field Voltage Regulator Assembly	Filters low frequency ripple from +28 v and -140 v supplies.	464692-150	Armament Rack
16	-140 Volts Direct Current Power Filter	Filters high-frequency ripple from -140 v supply.	464791-151	Radar Rack
17	+300 V & +150 V D. C. Field Voltage Regulator Assembly	Filters low-frequency ripple from +300 v and +150 v supplies.	464792-150-MD 1	Armament Rack
18	+150 Volts Direct Current Power Filter	Filters high-frequency ripple from +150 v supply.	464891-150	Armament Rack
19	400-Hz 1600-Hz Field Voltage Regulator Assembly	Regulates a-c voltages and provides over-voltage/under-voltage protection.	Jack & Heintz 51117-004 (Hughes 464892-154)	C.N. & L. Rack
20	+150 Volts Direct Current Power Filter	Filters ripple frequency from +150 v supply.	464991-150	Radar Rack
21	400-Hz & 1600-Hz Field Voltage Regulator Assembly	Regulates a-c voltages and provides over-voltage/under-voltage protection.	464992-150	C.N. & L. Rack



F = Field

*115 V 1600 Hz supplies power for under-voltage regulation and tube heaters.

FIGURE 5-2

BASIC POWER SUBSYSTEM DISTRIBUTION--NOT [illegible]DING OV/UV FUNCTIONS AND TIMING/SWITCHING CI[illegible]UITRY

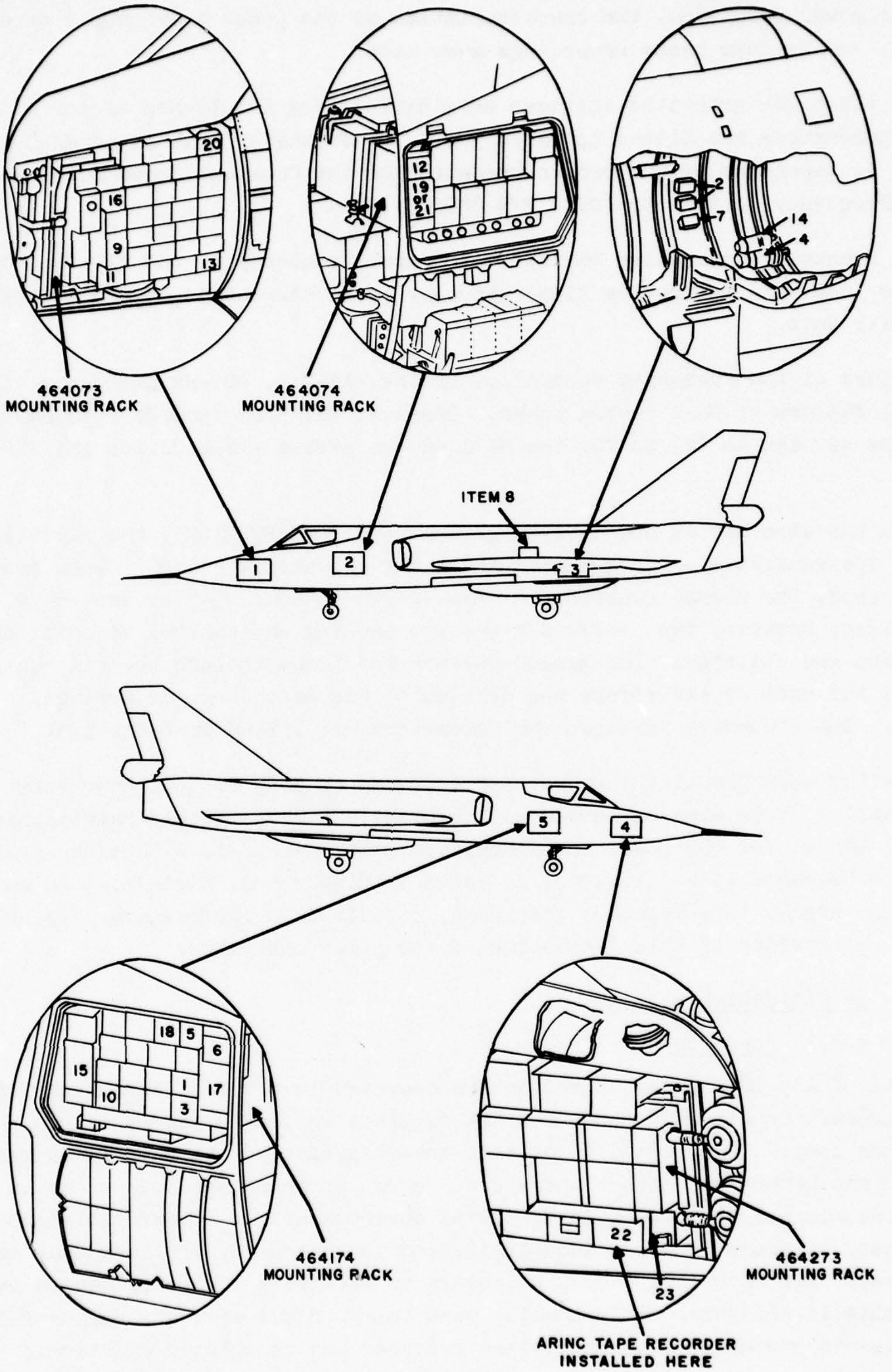


FIGURE 5-3

AIRCRAFT LOCATION OF POWER-SUBSYSTEM UNITS

the basic power subsystem, the characteristics of the power they supply were observed, and in some cases recordings were made.

The six basic generated voltages originating from the Hughes Aircraft Company generators are listed in Table 5-2. The frequency control of MA-1 a-c voltages is dependent on the proper operation of the Constant Speed Drive unit and the Frequency Controller (CVAC P/N 689305).

The Frequency Controller samples the output frequency of the 115-Vac, 400-Hz generator (Convair) to provide fine-frequency speed correction to the Constant Speed Drive unit.

Failure of the Frequency Controller or the 115-Vac, 400-Hz generator will result in failure of MA-1 system power. Observed failures include frequency excursions as high as 423 Hz for the MA-1 400-Hz system (1692 Hz for the 1600-Hz system).

When the aircraft is operated on ground power (AF/ECU-10M), the six basic voltages are generated and regulated within the ground-power unit. When ground power is used, the normal functions of P/N 464892/464992, 464692, and 464792 are not utilized; however, the over/under-voltage sensing and control circuits of these units are utilized. The ground-measurement tasks include the six basic voltages, but most of the effort was devoted to the secondary, or derived, voltages. The secondary voltages and parameters are listed in Table 5-3.

Detailed operational theory was not included as part of the power subsystem investigation. This area is adequately covered in the MA-1 Field Maintenance Technical Manual for the power subsystem, T.O. 11F1-MA1-12-1, 1 November 1961, Revised 16 November 1964. However, as shown in Figure 5-2, the system is unusually complex and highly interrelated; therefore, circuit descriptions are presented wherever appropriate in this discussion of the power subsystem.

5.3 Investigation Methods

5.3.1 Approach

Units of the MA-1 power subsystem are operated in three different environments: in the aircraft on aircraft power, in the aircraft on ground power, and in the maintenance shops. One objective of this investigation was to compare equipment operation and determine whether there was a correlation between events (such as voltage transients) that occur in the three environments. If correlation could be established, it would simplify identifying and isolating any problems that might be observed. For this task it was necessary to acquire a recording device capable of operating in all three environments, especially in the aircraft during flight. ARINC Research purchased a magnetic-tape recorder and associated electronic components that were packaged and used in several aircraft during flight lists.

TABLE 5-2

PARAMETERS OF BASIC GENERATED VOLTAGES OF POWER-SUBSYSTEM

Voltage	Function Frequency	Phase	Generator Part Number	Load Current In Amperes				Level Tolerance		Harmonic Distortion	
				Unit Rating	System Load*	Test Loads** 50%	Test Loads** 100%	Specification	Measured†	Specification	Measured†
115 Vac	400 Hz	A	31056-002	8.7	5.4	4.2	8.5	±2 Volts	-3 + 4	5% Total	
115 Vac	400 Hz	B	31056-002	8.7	6.1	4.2	8.5	±2 Volts	-3 + 4	Harmonic Distortion	
115 Vac	400 Hz	C	31056-002	8.7	6.5	4.2	8.5	±2 Volts	-3 + 4		
115 Vac	1600 Hz	Single Phase	31056-002	63.8	38.5	33.0	66.0	±2 Volts	-2 + 3		
										Noise Tolerance	
+28 Vdc	-	-	31056-002	60.0	26.5	27.0	55.0	±0.28 Volts	-1.8 + 0.02	4V P-P	80 Volts
+300 Vdc	-	-	464689-151	3.5	1.5	1.8	3.6	+3 Volts	-5.0 + 3.0	300 Mv P-P	1.3 Volts
+150 Vdc	-	-	464689-151	6.5	5.5	3.1	6.0	±1.5 Volts	-3.0 + 2.8	200 Mv P-P	500 Mv P-P
-140 Vdc	-	-	464689-151	4.0	3.6	2.0	3.9	±1.4 Volts	-3.1 + 2.2	200 Mv P-P	800 Mv P-P

*Normal Aircraft MA-1 System Loads.

**Measured Test-Load Voltage (Levels Within Tolerance) At Model LS-440 Load Bank.

†Measured Extremes in an Operational System (T-121 Digital Voltmeter).

TABLE 5-3

GENERAL PARAMETERS OF SECONDARY VOLTAGES

Secondary Voltage	Unit Number (464——)	Derived From	Referenced to	Maximum A-C Component
-250 Vdc	192	115V, 1600 Hz	+300 Vdc	200 Mv P-P
+100 Vdc (Reference)	292	+300 Vdc	+300 Vdc	70 Mv P-P
-140 Vdc (Reference)	292	-250 Vdc	+100 Vdc (Ref)	100 Mv P-P
+50 Vdc (Transistor)	326	115V, 1600 Hz	Internal Reference	200 Mv P-P
-50 Vdc (Transistor)	326	115V, 1600 Hz	Internal Reference	200 Mv P-P
-15 Vdc	326	-50 Vdc	No Reference (Zener Diodes)	100 Mv P-P
55/115 V, 1600 Cycle (Reference)	491	115V, 1600 Hz	+300 Vdc	
The voltages below are generated in units which are not part of the power subsystem.				
+50 Vdc (IR)	746	115V, 400 Hz, ϕ C	Internal Reference	200 Mv P-P
-50 Vdc (IR)	746	115V, 400 Hz, ϕ C	Internal Reference	200 Mv P-P
+50 Vdc (Computer)	489	+100 Vdc Reference	+100 Vdc Reference	Unknown

A study of the power subsystem and its operation on the aircraft* shows that with the exception of the source of basic generated voltages, there is little difference between operation on aircraft power and operation on ground power. In both cases the loads, regulation, etc., are the same. This lack of difference made it possible to obtain much of the needed data from an aircraft operating on ground power. One aircraft was made available to be used with the Fault Detection Tester (FDT), which was being tested at Dover AFB. Aircraft serial number 500 was designated to be used for the FDT tests. Extensive work had been performed to optimize the power subsystem of this aircraft. During the FDT test, ARINC Research observed and recorded voltage waveforms for this optimized system.

The investigation of the power subsystem consisted of measuring and recording voltages in the aircraft on both ground and aircraft power, making in-flight recordings as aircraft availability would permit, and recording specific voltages of the subsystem in the shop mock-ups. Direct monitoring was accomplished by connecting a Tektronix storage oscilloscope, type 564, to units of the power subsystem in the maintenance shops or in aircraft on the ground. Other observations were made by recording voltage waveforms on magnetic tape and then playing back the tapes into the storage oscilloscope. This method was used primarily for in-flight recordings. However, the ability to store and play back the tape on the recorder was also used to a limited degree in the aircraft during ground tests

*In-flight recordings were made using several operational F-106 aircraft.

and during tests in the shop. It was thus possible to make permanent photographic records of some transitory waveforms that otherwise could not be photographed.

The flight-test phase of the measurement program also included recording data on MA-1 performance and follow-up maintenance actions. This information was required for analysis of F-106/AWCIS power-subsystem characteristics in the operational environment. The format for collection of flight-recorder data is shown in Figure 5-4.

The data collected and tabulated throughout the flight test phase of this program included the full range of system parameters and reflect the real-time relationships of events.

5.3.2 Equipment Used

5.3.2.1 Magnetic Tape Recorder - A magnetic tape recorder was purchased from Kinelogic Corporation to be used for in-flight recordings of voltages in the power subsystem. The recorder included the following components:

- Tape Transport
- Record and Playback Head
- Recorder Operation Logic
- Seven Direct Record Amplifiers
- Two Direct Playback Amplifiers
- Bias Oscillator
- Drive Motor Inverter
- Inverter Voltage Regulator

A special chassis was constructed at the ARINC Research laboratory in Annapolis, Maryland, to house the recorder components. All interconnecting wiring for the above components, additional control circuitry, and external wiring were installed in the ARINC Research laboratory.

The recorder package was designed so that it could be installed in an F-106, for in-flight recordings, in the space normally occupied by the 464296 unit. This provided a convenient location with easy access to the power-subsystem test point located in the 464489 unit. No aircraft-wiring changes were required. The wiring required for normal operation of the MA-1 computer subsystem was included in the recorder package.

The recorder package was designed for both automatic and manual operation. Automatic operation was necessary for in-flight recordings, and manual operation was used for playback and during the recording of other than in-flight operation.

ARINC RESEARCH CORPORATION
FLIGHT RECORDER PROGRAM
WORK ORDER 711.01

Date________ T.O. Time______ A/C No.______ Pilot______ Mission________________ Total Flight Time______

Events/Modes During Record Time________________

MA-1 Performance or Degradations________________

Maintenance Actions________________

Comments________________

ARINC Tape No.______ Recorder Installation______ Pick Up Cable No. ______ Recorder Logic______

Channel No.	Source	Unit/Location	Test Point	Return Line	Scale Factor	Metered Value	Remarks
1							
2							
3							
4							
5							
6							
7							

Notes:

FIGURE 5-4

DATA COLLECTION FORM

Automatic operation was initiated when the nose-wheel-well door closed and continued until the end-of-tape signal was sensed by the recorder control circuitry.

The electrical and mechanical specifications of the tape recording equipment used in this program are as follows:

<u>Mechanical</u>

Tape Speed: 7.5 ips primary
15 ips via inverter frequency change (switched electronically)

Number of Channels: Seven Record
Seven Playback

Tape Length: 600 feet

Tape Type: 0.5-inch wide
1.1-mil thick 0.92-mil mylar base, 0.18-mil oxide coating

Record Time: 16 minutes at 7.5 ips

Flutter: 2.0 percent maximum peak to peak; Pass band - 0.2 Hz to 2.5 Hz, 7.5 ips speed

Size: 7 inches by 6 inches by 3 7/16 inches (exclusive of ARINC Research modifications)

Weight: 5.5 pounds (exclusive of ARINC Research modifications)

<u>Electrical</u>

Power: +27 Vdc +3 volts, approximately 0.7 amp

Frequency Response: 100 Hz to 32 KHz +3 dB at 7.5 ips*

Input Sensitivity: 0.1 to 1.5 volts rms

Input Impedance 100K ohm minimum (unbalanced)

Bias Oscillator Frequency: 750 KHz

Output Impedance: 100 ohms

Output Level: 1 volt rms, nominal, into 1 kilohm minimum

5.3.2.2 <u>Additional Equipment</u> - In addition to the flight-recorder package, the following items were required for ground measurements and recorder playback:

- Tektronix Model 56A, Storage Oscilloscope
- Tektronix Model C-19, Oscilloscope Camera

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*This was the frequency response used by ARINC Research during this study, although the unit is capable of operation to 300 KHz depending on tape speed.

* Hewlett-Packard Model 428B, Clamp-on D-c Ammeter
* Tektronix Type P6016 A-c current probe
* Voltmeters, Harmonic Analyzer, Frequency and Modulation meters available in the Air Force inventory at Dover
* Miscellaneous, patch cables, equipment carts

5.4 Findings Related to D-C Power

Some of the problems in the power subsystem are associated with the secondary regulator-filter units and circuitry (unit P/Ns 464092, 464192, 464292, 464591, 464791, 464891, and 464991), which are highly interrelated and dependent on each other for proper performance. In Figure 5-2, it can be seen that these units provide reference voltages and operating bias voltages (which are derived from sources external to the units). These conditions create feedback loops, making the identification of specific problems, such as transients, extremely difficult.

The 115-volt, 1600-Hz source also provides inputs to this group of units. These include tube heater voltage and power to compensate for undervoltage excursions in the related output voltage through the series clampax circuits in the 464092, 464591, and 464791 units. The series clampax circuits are designed to compensate for transient low-voltage conditions of the -140, +150 and +300 Vdc. These d-c voltages originate in the field regulators. The purpose of the parallel or shunt clampax circuits is to maintain the incoming voltage at a specified maximum level.

The clampax configuration gives rise to a problem whenever there is a momentary loss (less than 50 seconds) of the d-c source voltages from the field regulator units. The load imposed on the series clampax and transformer-rectifier supply (fed by the 115-volt, 1600-Hz source) as a result of this momentary loss causes an immediate catastrophic failure of components in the 115-volt, 1600-Hz transformer and rectifier-filter circuits. A secondary result of this momentary failure is a short in the power transformer, causing a power dump of the 115-volt, 1600-Hz source and consequently loss of the entire power subsystem. The loss of transformer T1, known to be a high failure item, is typical of this type of failure.

Several failed transformers were recovered as failed parts during earlier ARINC Research reliability studies. Examination showed that the transformer case had exploded, with a resultant loss of potting tar.

Overload protection is not provided to the transformer and rectifier-filter circuits. If protection were provided for these circuits, the MA-1 system could in many cases complete an operational mission with some possible degradation of performance.

An additional problem associated with the clampax units is the abnormally high replacement rate of the type-609A regulator tube. The failure mode of most of these tubes was complete loss of emission. The failure of one or two of these tubes does not result in complete failure of the unit functions, because of the parallel configuration; however, ARINC Research has found that the noise levels recorded on units with failed tubes were much higher than normal.

In one case during the ARINC Research measurement program, a 591 unit was discovered in an operational aircraft in which three of the four series clampax regulator tubes had failed. Tube-tester checks showed no emission at all for any of the three tubes. The only indication of the failure of this 591 unit was the high level of noise and transients recorded on the +300 Vdc power buss in the aircraft. Separate clampax circuits, two for each voltage, are used to filter the +300-Vdc and +150-Vdc power in the aircraft. One clampax circuit is located forward and one aft in the aircraft. When voltage noise is checked in the aircraft at the front of one of these clampax units, the noise may be within tolerance. However, because of long lead lengths between units, the noise level at another MA-1 system unit may exceed the specified tolerance. To alleviate this problem, a more complete noise check at several units may be required.

Another problem related to the clampax circuits is illustrated in Figure 5-5. During certain loading variations caused by system-mode switching, high-level oscillations occur on the +150 Vdc line.

A cursory investigation of the effects of adding additional filter capacitance across the outputs of units 326, 192, 791, 991, 891, 092, and 591 was not fruitful. The additional capacitance in most cases did reduce the noise level; however, the added capacitance created phase shift in the feedback loops, which made the regulator-clampax circuitry even more susceptible to oscillation. Further investigation into this oscillation problem is required.

5.4.1 Voltage Problems

The power-subsystem voltages, both generated and conditioned, were observed and photographed in both aircraft and shop environments. Tables 5-4 and 5-5 list the voltages recorded and the location in which these photographic recordings were made. Where available, the specification for maximum allowable ripple is also listed for the applicable voltages. Out-of-tolerance conditions shown in tables 5-4 and 5-5 are discussed later in this section of the report.

All measurements listed in Table 5-4 were made in aircraft serial number 500, which had been specially prepared for tests of the Fault Detection Tester (FDT) at Dover AFB. The voltages observed in this aircraft represent the optimum for an F-106 aircraft because extensive work was performed to prepare the power subsystem of this aircraft for the FDT tests.

Measurements shown in Table 5-5 were made in the various maintenance shops (radar, computer, electric, etc.) as identified in the table. Specifications for maximum permissible ripple on each voltage are provided for comparison.

TABLE 5-4
POINTS MONITORED IN AIRCRAFT NUMBER 500
(D-C VOLTAGES)

Test Points Monitored	+28Vdc	-140Vdc	+150Vdc	+300Vdc	-250Vdc	-250Vdc*	+100V Ref.	-140V Ref.	-140V Ref.*	-140V Ref.**	-140V Ref.***	+50V (Transistor)	-50V (Transistor)	-15Vdc	+50V Ref.	+50V (IR)	-50V (IR)	+75V	+75V***
Maximum Permissible Noise (Millivolts, Peak-to-Peak)	4	200	200	300	200	200	70	100	100	100	100	200	200	100	Unk.	200	200		
UV-OV Relay Assembly, 464062	700	300	100	60	120														
-250V Power Supply, 464192		170			60	40*													
+100V, -140V Regulator, 464292				80	60		100	180	1.9	480									
+50V Power Supply, 464326																			
115/55V, 1600-112 Regulator, 464491				40															
+300V D-C Filter, 464591		40																	
-140V D-C Filter, 464791		50			40														
+150V D-C Filter, 464991		40	20																
Radar Self-Test Meter, 464096							120	300			720	300	160	30	60	150		200+75on	540+75on
Radar Synchronizer, 464103		30	150	270	90														
Radar Indicator, Video and AZ Sweep Amplifier, 464195		600	100		40														
Stable Platform, 464289		250	320																
Radar Indicator		350	300																
Radar Indicator, Sweep Generator, 464389		90	100	360	700														
Computer Clock Pulse Generator, 464489				100	70										50				
IR Range Computer, 746							50					120	40			140	40		
Tacan Units:																			
Range Transmitter		20	160	220															
Bearing Transmitter		30	80	130															

*Mode switched to spotlighting IR target in hand control.

**Switched mode to radar hand control.

***Switched to visual identification mode.

Note: Unless otherwise specified, all voltages are in millivolts, peak-to-peak.

TABLE 5-5

RIPPLE VOLTAGE MEASUREMENTS MADE IN SHOP MOCK-UP (D-C VOLTAGES)

Voltages	Maximum Allowed Ripple	Radar Shop Mock-Up	Electric Shop Test Stand		±50V Power Supply 464326	
			No Load	100% Load	Good Unit	Defective Unit
+28 Vdc	4 volts	4 volts*				
-140 Vdc	200	800				
+150 Vdc	200	240	260	500		
+150V Field			380	1.3 volts		
+300 Vdc	300		900	1.3 volts		
+300 Field			360	1.4 volts		
-250 Vdc	200	460				
+100V (Ref)	70	280				
-140V (Ref)	100	560				
+50V (Transistor)	200	560			20	150
-50V (Transistor)	200	960			20	160
-15V	100	590				
+50V (Ref)	Unknown					
+50V (IR)	200					
-50V (IR)	200					
+75V						
-75V						

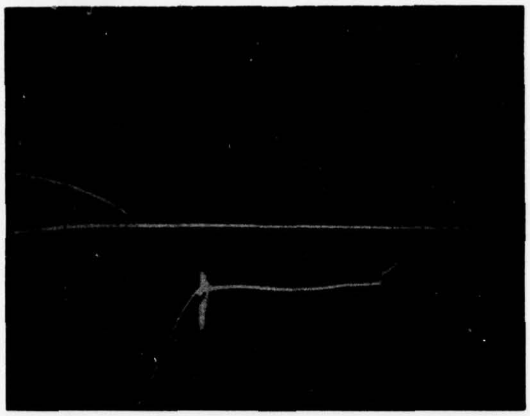
Unless otherwise specified, all voltages are in millivolts peak to peak.
*In addition to the 4 volts ripple, the d-c level shifts approximately 1-1/2 volts.

The voltage conditions noted during this program are discussed briefly below.

5.4.1.1 <u>+28 Vdc</u> [Maximum Allowable A-C Peak-to-Peak Ripple 4 volts as specified in T.O. 11F1-MA-1-12-1]. The +28 Vdc line was monitored in aircraft number 500 with a Tektronix storage oscilloscope, type 564. At times transients were observed, but attempts to photograph these transients* using only the oscilloscope were unsuccessful. Therefore, the magnetic tape recorder was used to monitor these voltages, and photographs were made during subsequent playback of the tapes. Figure 5-6 illustrates one condition recorded during a three-minute tape run when radar on/off mode switching was taking place. Figure 5-7 is another recording made during a tape run in an aircraft. In this case, a transient of +80 volts was recorded; but because of saturation of the recorder amplifiers, the total amplitude of this transient is not shown. This transient

*The quality of the photographs of the worst-case voltage conditions was such as to preclude reproduction in this report.

Direct Oscilloscope Recording in Maintenance Shop



+150 Vdc, no load
Electric Shop Mock-up Test Stand
Amplitude: 2 V/cm

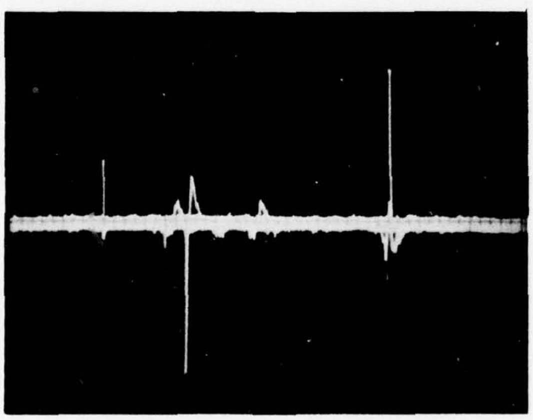
+150 Vdc, 100% load
Electric Shop Mock-up Test Stand
Amplitude: 2 V/cm

Sweep speed: 1 sec/cm

FIGURE 5-5

**COMPARISON OF THE +150 Vdc:
NO LOAD AND FULL LOAD**

Magnetic Tape Recording In Aircraft S.N. 500



+28 Vdc
Amplitude: 10 V/cm

Denotes Specific Limits

Sweep speed: 50 ms/cm

FIGURE 5-6

TRANSIENTS ON THE +28 Vdc LINE

is being coupled into the 115-Vac 1600-Hz reference signal. The +28 Vdc and 115-Vdc 1600-Hz voltages, recorded on magnetic tape during flight, were observed on a dual-trace oscilloscope; they indicate that when the transient on the +28 Vdc occurs, a transient is also injected into the 115-Vdc 1600-Hz reference voltage (see Figure 5-8).

Magnetic-tape recordings of the voltage in the radar shop mock-up also show the presence of ripple (4 volts peak to peak); however, although not shown, a shift in the d-c reference of 1-1/2 volts was observed when the gyro heat circuit in the radar antenna was cycled on and off.

5.4.1.2 -140 Vdc [Maximum Allowable Ripple 200 Millivolts Peak to Peak (mV P-P)]. Measurements in the aircraft showed that the allowable maximum ripple was exceeded in the 062 unit (Figure 5-9), the 195 unit (Figure 5-10), the 289 unit (Figure 5-11) and the 389 unit (Figure 5-12).

First recordings of the -140 Vdc in the radar shop mock-up (with an oscilloscope sweep speed of 0.2 milliseconds/cm) appeared to be within specifications, as shown in the upper trace of Figure 5-13. However, re-examination at a lower sweep speed (5 milliseconds/cm) revealed that the a-c component (see Figure 5-14, lower trace) was 800 millivolts peak to peak. This was the result of one noise level of 180 mV riding on a 60-Hz signal that is introduced on the -140 Vdc in the radar shop mock-up.

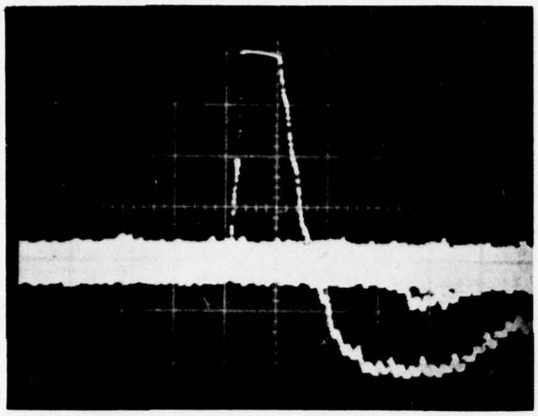
5.4.1.3 +150 Vdc [Maximum Allowable Ripple 200 Millivolts Peak to Peak (mV P-P)]. Two of the recordings made in the aircraft indicate the P-P limits are exceeded. One recording was made in the 289 unit (see Figure 5-11 lower trace), and the other in the 389 unit (see Figure 5-15, upper trace). In both cases the levels recorded were 300 mV or more.

The +150 Vdc voltage in the radar shop was found to have a ripple level of 240 mV P-P (see Figure 5-16, lower trace). When this same voltage was observed on the electric shop test stand under both load and no-load conditions, the measured noise increased from 260 mV P-P under no-load (Figure 5-17, upper trace) to 500 mV P-P under 100% load (Figure 5-18, upper trace).

Figure 5-5 shows the +150 Vdc as observed in the electric-shop test stand. The slow oscillation shown was later corrected by replacing a gassy tube in the 991 unit. This condition was not observed when the equipment was operating under 50-percent or 100-percent loads. Figure 5-19 shows the slow recovery time of the +150 Vdc caused by the defective tube.

5.4.1.4 +300 Vdc [Maximum Allowable Ripple 300 Millivolts Peak to Peak (mV P-P)]. The +300 Vdc line was monitored in several units in the aircraft. However, the allowable limits were exceeded at only one unit, P/N 464389. In this unit the level was 360 mV P-P, as shown in Figure 5-20, lower trace.

Magnetic Tape Recording In Aircraft



+28 Vdc

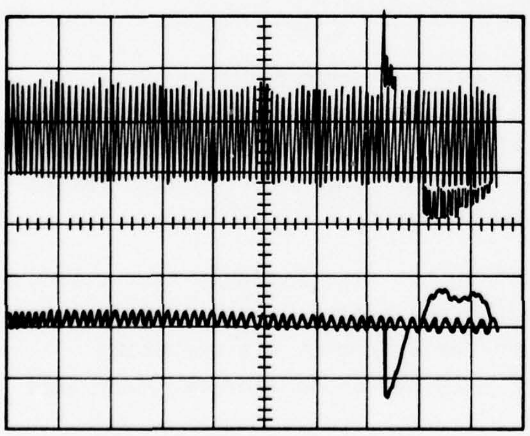
Amplitude: 20 V/cm

Sweep speed: 2 ms/cm

FIGURE 5-7

TRANSIENTS ON THE +28-Vdc LINE

In-flight Recording



115V 1600 cycle reference

Amplitude: 200 V/cm

+28 Vdc

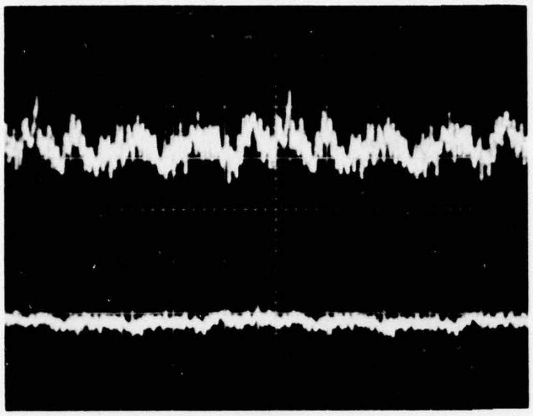
Amplitude: 20 V/cm

Sweep speed: 5 ms/cm

FIGURE 5-8

SWITCHING TRANSIENTS IN THE 28-Vdc DISTRIBUTION SYSTEM AND THE 115-V, 1600-Hz REFERENCE, MODULATED BY TRANSIENTS GENERATED IN THE 28-Vdc SYSTEM

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc
P/N 464062 Unit
Amplitude: 100 mV/cm

+150 Vdc
P/N 464062 Unit
Amplitude: 100 mV/cm

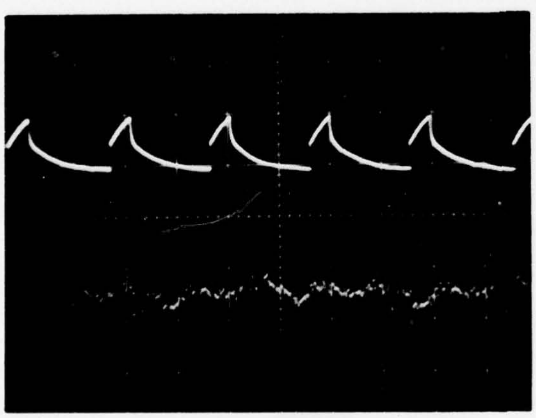
Denotes Specific Limits

Sweep speed: 0.5 ms/cm

FIGURE 5-9

RIPPLE PRESENT IN THE 062 UNIT

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc
P/N 464195 Unit
Amplitude: 500 mV/cm

-140 Vdc
P/N 464791 Unit
Amplitude: 50 mV/cm

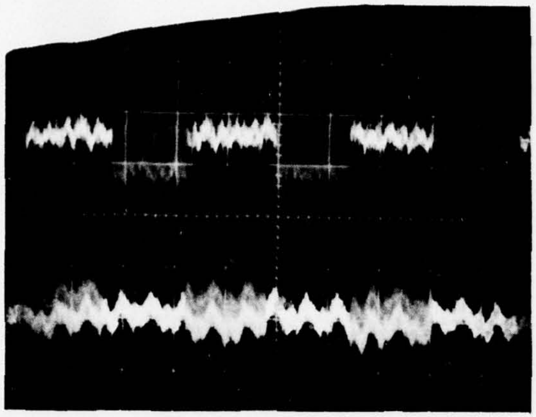
Denotes Specific Limits

Sweep speed: 0.5 ms/cm

FIGURE 5-10

VOLTAGE WAVEFORMS OF THE -140-Vdc DISTRIBUTION

Direct Oscilloscope Recordings in Aircraft S.N. 500



-140 Vdc

P/N 464289

Amplitude: 100 mV/cm

+150 Vdc

P/N 464289

Amplitude: 200 mV/cm

Sweep speed: 2 ms/cm

FIGURE 5

VOLTAGE WAVEFORMS IN THE 289 UNIT

Direct Oscilloscope Recording in Aircraft S.N. 500

-140 Vdc

P/N 464389 Unit

Amplitude: 100 mV/cm

-140 Vdc

P/N 464591 Unit

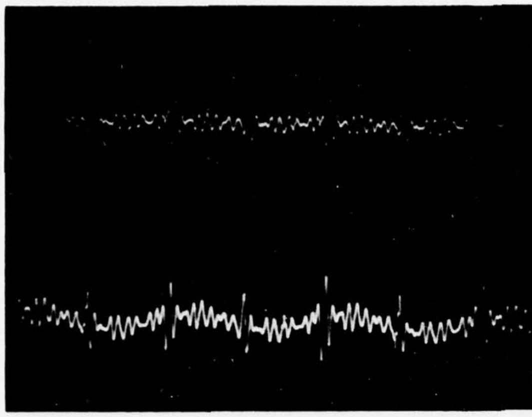
Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-12

VOLTAGE WAVEFORMS OF THE -140-Vdc DISTRIBUTION

Direct Oscilloscope Recordings in Maintenance Shop



-140 Vdc
Radar Shop Mock-Up
Amplitude: 200 mV/cm

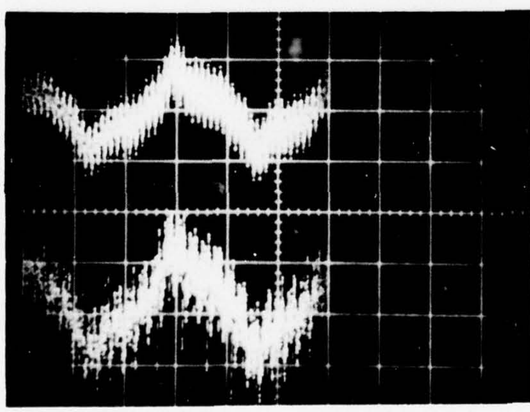
-140-Vdc Reference
Radar Shop Mock-Up
Amplitude: 200 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-13

VOLTAGE WAVEFORMS FOR THE -140 Vdc AND THE -140-Vdc REFERENCE

Direct Oscilloscope Recordings in Maintenance Shop



-140-Vdc Reference
Radar Shop Mock-up
Amplitude: 200 mV /cm

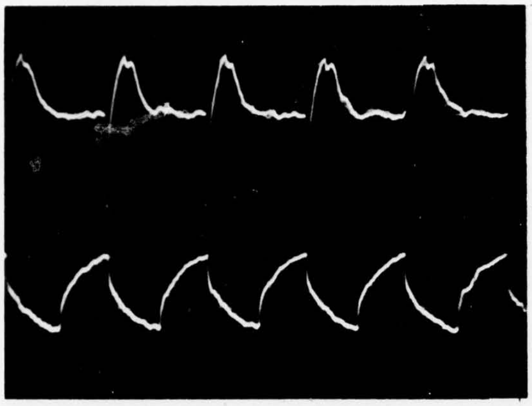
-140 Vdc
Radar Shop Mock-up
Amplitude: 200 mV/cm

Sweep speed: 5 ms/cm

FIGURE 5-14

VOLTAGE WAVEFORMS FOR THE -140 Vdc AND THE -140-Vdc REFERENCE

Direct Oscilloscope Recordings in Aircraft S.N. 500



+150 Vdc
P/N 464389 Unit
Amplitude: 100 mV/cm

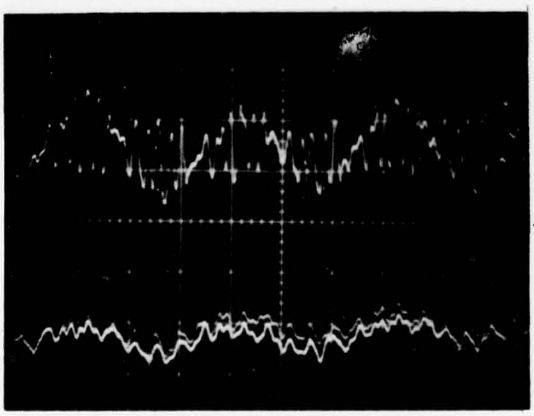
+150 Vdc
P/N 464103 Unit
Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-15

VOLTAGE WAVEFORMS IN THE +150-Vdc DISTRIBUTION

Direct Oscilloscope Recordings in Maintenance Shop



-250 Vdc
Radar Shop Mock-up
Amplitude: 200 mV/cm

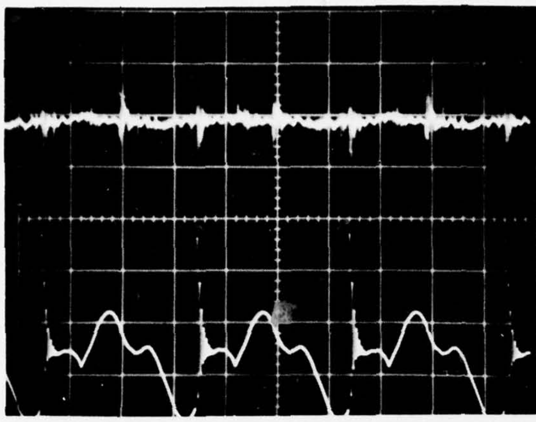
+150 Vdc
Radar Shop Mock-up
Amplitude: 200 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-16

VOLTAGE WAVEFORMS OF THE -25-Vdc AND +150-Vdc DISTRIBUTION

Direct Oscilloscope Recording in Maintenance Shop



+150 Vdc, No Load

Electric Shop Mock-up Stand
Test Point

Amplitude: 200 mV/cm

+150-V Field, No Load

Pin 8 of AR 203

Electric Shop Mock-up

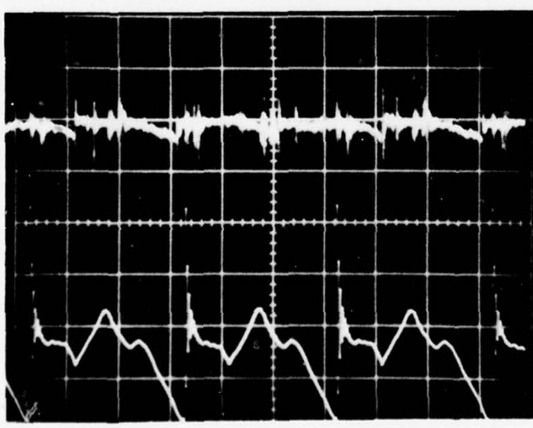
Amplitude: 100 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-17

VOLTAGE WAVEFORMS OF THE +150-Vdc OUTPUT AND THE +150-V FIELD VOLTAGE

Direct Oscilloscope Recording in Maintenance Shop



+150 Vdc 100% Load

Electric Shop Mock-up Stand
Test Point

Amplitude: 200 mV/cm

+150-V Field, 100% Load

Pin 8 of AR 203

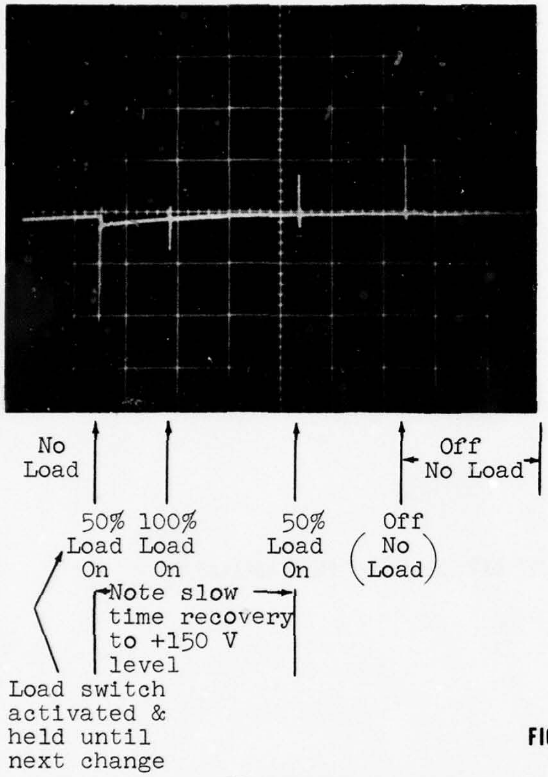
Amplitude: 100 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-18

VOLTAGE WAVEFORMS OF THE +150-Vdc OUTPUT AND THE +150-V FIELD VOLTAGE

Direct Oscilloscope Recording in Maintenance Shop



+150 Vdc Load Switching

Electric Shop Mock-up Test Stand

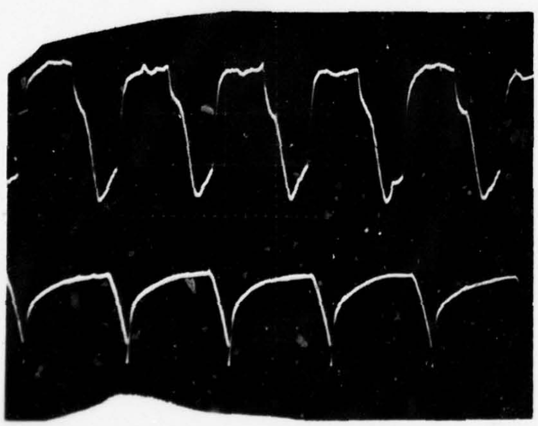
Amplitude: 50 v/cm

Sweep speed: 0.5 seconds/cm

FIGURE 5-19

SWITCHING TRANSIENTS AND REGULATOR RECOVERY FOR THE +150-Vdc DISTRIBUTION

Direct Oscilloscope Recording in Aircraft S.N. 500



+300 Vdc

P/N 464103 Unit

Amplitude: 100 mV/cm

+300 Vdc

P/N 464389 Unit

Amplitude: 200 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-20

RIPPLE VOLTAGE WAVEFORMS OF THE +300-Vdc IN THE 103 AND 389 UNITS

The +300 Vdc line was also monitored at the test points in the electric-shop test stand. The ripple present on the +300 Vdc supply under no load was 900 mV P-P (Figure 5-21, upper trace). When the load was increased to 100-percent, the ripple increased to 1.3 volts (Figure 5-22, upper trace). Although in both cases the specification was exceeded, since standard test procedures do not require the measurement of ripple voltage,this condition would go undetected and shop maintenance personnel would consider this to be a good unit.

5.4.1.5 <u>-250 Vdc</u> [Maximum Allowable Ripple 200 Millivolts Peak to Peak (mV P-P)]. The maximum allowable ripple was found to be exceeded in only one unit (P/N 464389) of the several units tested in the aircraft. The ripple was 700 mV P-P as shown in Figure 5-23, lower trace. The -250 Vdc voltage at this point resembles a sawtooth waveform.

When the -250 Vdc was observed in the radar shop, the ripple was found to be 460 mV P-P (see Figure 5-16, upper trace), but the waveform did not resemble that seen in the aircraft. In the shop, one noise component of about 300 mV P-P appears to be riding on a 1600-Hz signal.

5.4.1.6 <u>+100 Vdc Reference</u> [Maximum Allowable Ripple 70 Millivolts Peak to Peak (mV P-P)]. The maximum ripple level is exceeded in two of the locations monitored on the aircraft. These are shown in Figure 5-24, lower trace (292 unit) and Figure 5-25, lower trace (096 unit).

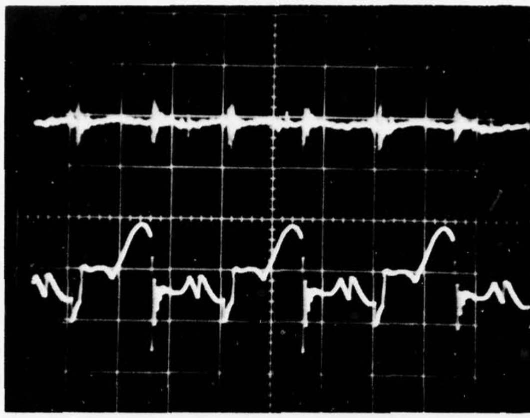
The noise level of the +100 reference voltage was recorded in the radar shop at 280 mV P-P as shown in Figure 5-26, lower trace. (The presence of 1600 Hz is also indicated.)

5.4.1.7 <u>-140 Vdc Reference</u> [Maximum Allowable Ripple Specification 100 Millivolts Peak to Peak (mV P-P)]. The -140 Vdc reference voltage was monitored in the aircraft and the ripple specification was found to be exceeded in several cases. (The source from which the -140V reference is derived (the 292 unit) had been repaired and tested in the shop mock-up just prior to the measurement program.) Figure 5-27, upper trace, shows the -140V reference as it appears at the test point on the 292 unit. The ripple (180 mV P-P) exceeds the specifications for the unit under normal operating conditions.*

During the aircraft measurements, it was noted that operation of the equipment in various modes produced some unusual waveforms on the -140V reference. When the operator changed mode to Spotlighting IR Target in Hand Control, the -140V reference experienced deviations as much as 1.9 volts, as shown in Figure 5-28, upper trace. When the equipment was switched to Radar Hand Control, the noise

*Also note the lower trace (-250 Vdc) in Figure 5-27, which is the source for the -140V Reference. No evidence of noise peaks are seen here, indicating that the noise on the -140V Reference does not originate at the source (-250 Vdc).

Direct Oscilloscope Recording in Maintenance Shop



+300 Vdc, No Load

Electric Shop Stand Test Point

Amplitude: 500 mV/cm

+300-V Field, No Load

Electric Shop

Pin 11 of AR 103

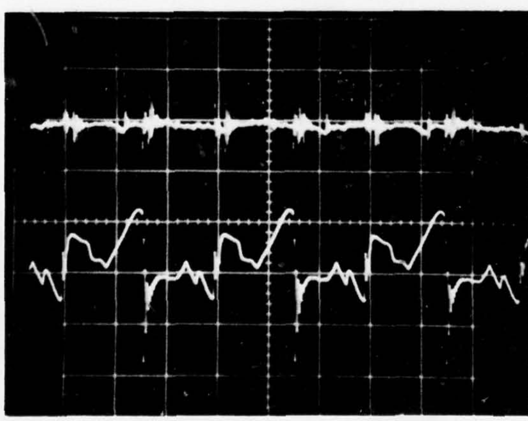
Amplitude: 100 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-21

RIPPLE VOLTAGE LEVELS OF THE +300-Vdc SYSTEM

Direct Oscilloscope Recording in Maintenance Shop



+300 Vdc, 100% Load

Electric Shop Stand Test Point

Amplitude: 500 mV/cm

+300 V Field , 100% Load

Electric Shop Stand

Pin 11 of AR 103

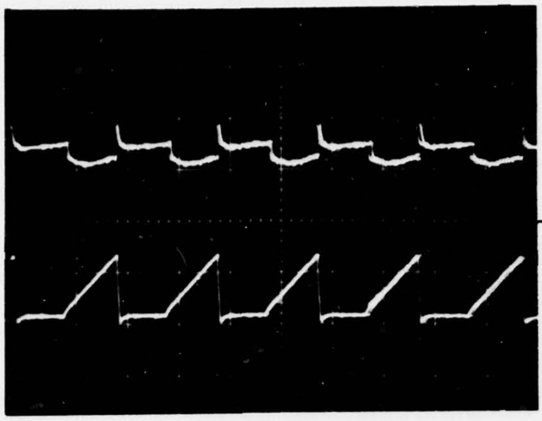
Amplitude: 100 mV/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-22

RIPPLE VOLTAGE LEVELS OF THE +300-Vdc SYSTEM

Direct Oscilloscope Recording in Aircraft S.N. 500



-250 Vdc
P/N 464103 Unit
Amplitude: 100 mV/cm

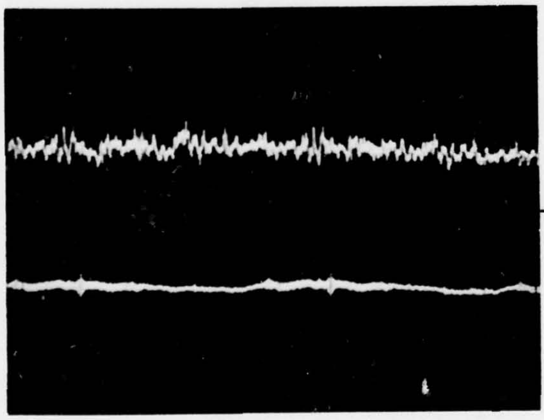
-250 Vdc
P/N 464389 Unit
Amplitude: 500 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-23

VOLTAGE WAVEFORMS FOR THE -250-Vdc SYSTEM AT THE 103 AND 389 UNITS

Direct Oscilloscope Recording in Aircraft S.N. 500



+300 Vdc
P/N 464292 Unit
Amplitude: 100 mV/cm

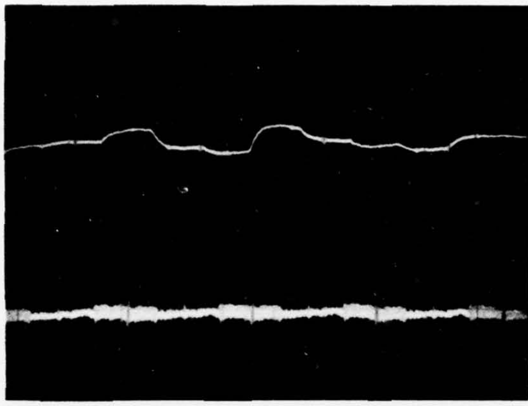
+100-Vdc Reference
P/N 464292 Unit
Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-24

NOISE PRESENT IN THE +300-Vdc AND +100-Vdc REFERENCE

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc Reference
P/N 464096 Unit
Amplitude: 500 mV/cm

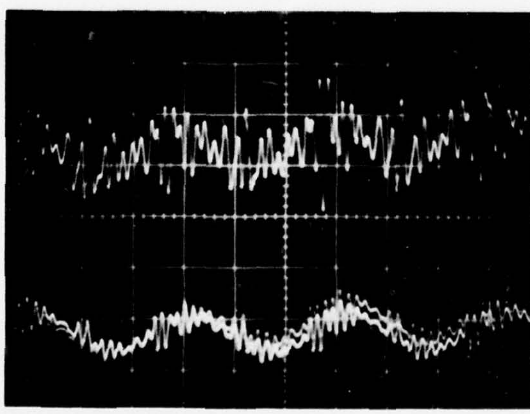
+100 Vdc Reference
P/N 464096 Unit
Amplitude: 100 mV/cm

Sweep speed: 1 ms/cm

FIGURE 5-25

NOISE AND RIPPLE PRESENT IN THE -140-Vdc REFERENCE

Direct Oscilloscope Recording in Maintenance Shop



-15 Vdc
Radar Shop Mock-Up
Amplitude: 200 mV/cm

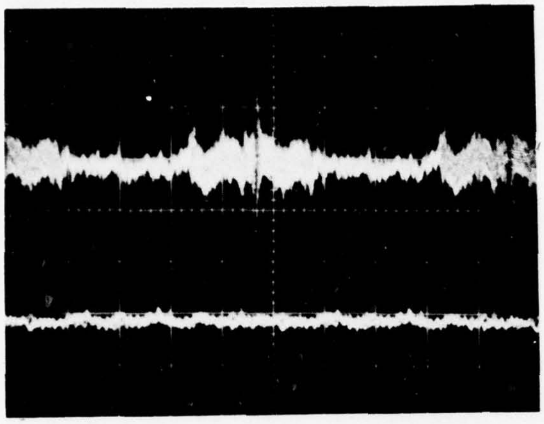
+100-Vdc Reference
Radar Shop Mock-Up
Amplitude: 200 mV/dm

Sweep Speed: 0.2 ms/cm

FIGURE 5-26

NOISE AND RIPPLE PRESENT IN THE -15-Vdc AND +100-Vdc REFERENCE DISTRIBUTION

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc reference

P/N 464292 Unit

Amplitude: 50 mV/cm

-250 Vdc

P/N 464292 Unit

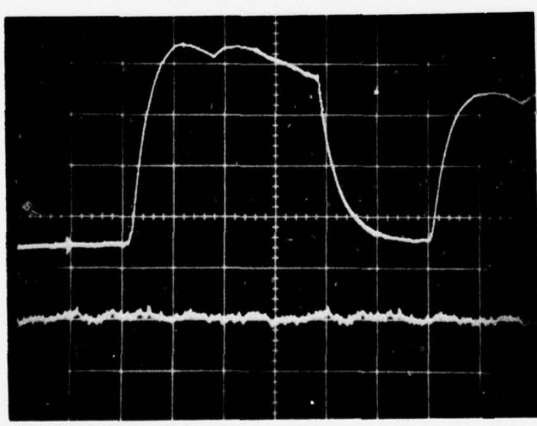
Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-27

NOISE PRESENT IN THE -14-Vdc REFERENCE AND THE -250-Vdc PRESENT AT THE 292 UNIT

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc Reference

P/N 464292 Unit

Amplitude: 500 mV/cm

-250 Vdc

P/N 464292 Unit

Amplitude: 100 mV/cm

Denotes Specific Limits

Sweep speed: 0.5 ms/cm

FIGURE 5-28

VOLTAGE WAVEFORMS FOR THE -140-Vdc REFERENCE AND THE -250-Vdc AT THE 292 UNIT (OPERATING MODE: SPOTLIGHT IR TARGET IN HAND CONTROL)

in the -140V reference was found to be 480 mV P-P (Figure 5-29, upper trace). Switching the equipment to the Visual Identification Mode produced a noise level of 720 mV P-P on the -140V reference, as shown in Figure 5-30.

The upper trace of Figure 5-14 shows the -140V reference as observed in the radar shop. This waveform does not resemble the waveforms observed in the aircraft. Note the presence of 60 Hz on the -140V reference in the radar shop.

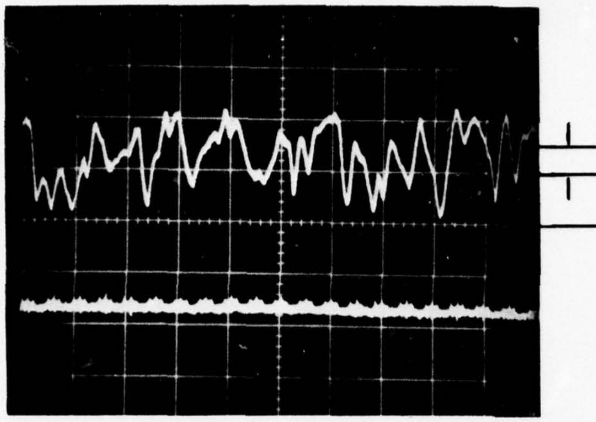
5.4.1.8 +50 Vdc (Transistor) [Maximum Allowable Ripple 200 Millivolts Peak to Peak (mV P-P)]. The lower trace of Figure 5-31 shows the +50 Vdc in the aircraft. The noise appears like blocks of pulses on the +50 Vdc. Also observed but not photographed were spikes with an amplitude of 300 mV P-P. The origin of these pulse blocks could not be determined, but they are of concern because the +50 Vdc is used in many critical circuits including new circuitry being added to the F-106.

Several good 326 units were observed in the electric-shop mock-up, and Figure 5-32, lower trace, shows the +50 Vdc in a typical unit. Noise shown in the photograph is about 20 mV P-P, well within specifications. One 326 unit, removed from an aircraft for control-stick chatter in the Assist mode, had approximately 40 mV P-P noise under no load (see Figure 5-33, lower trace). When the unit was placed under load, the +50 Vdc noise level increased to 150 mV P-P, as shown in the lower trace of Figure 5-34 (still within the specification). However, after repair, the noise level was reduced to approximately 20 mV P-P, as shown in Figure 5-32. When installed in the aircraft, the unit operated properly. This example indicates that the noise specification for this unit should be reduced to assure proper operation.

5.4.1.9 -50 Vdc (Transistor) [Maximum Allowable Ripple 200 Millivolts Peak to Peak (mV P-P)]. The upper trace of Figure 5-31 shows the -50 Vdc voltage as recorded on the aircraft. The noise appears like blocks of pulses on the -50 Vdc. The origin of these pulse blocks could not be determined but they are of concern because, as with the +50 Vdc, the -50 Vdc is used in many critical circuits, including new circuitry being added to the F-106.

Several good P/N 464326 units were observed in the electric shop mock-up; the noise level of a typical good unit is shown in Figure 5-32. The noise level of approximately 20 mV P-P is well within specifications. The same unit, described in the discussion of +50 Vdc, was found to have a noise level of approximately 40 mV P-P under no load (see Figure 5-33, upper trace), and 160 mV P-P under full load (see Figure 5-34), both within the specification. Unit repair also reduced the noise level of the -50 Vdc to approximately 20 mV P-P, as shown in Figure 5-32. When installed in the aircraft, the unit performed properly. Again, the noise specifications are not realistic.

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc Reference

P/N 464292 Unit

Amplitude: 200 mV/cm

+100 Vdc Reference

P/N 464292 Unit

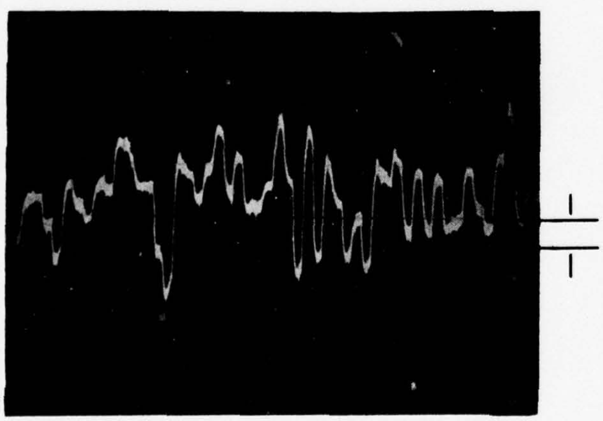
Amplitude: 100 mV/cm

Sweep speed: 5 ms/cm

FIGURE 5-29

VOLTAGE WAVEFORMS FOR THE -140-Vdc REFERENCE AND THE -250-Vdc AT THE 292 UNIT (OPERATING MODE: RADAR HAND CONTROL)

Direct Oscilloscope Recording in Aircraft S.N. 500



-140 Vdc Reference

P/N 464096 Unit

Amplitude: 200 mV/cm

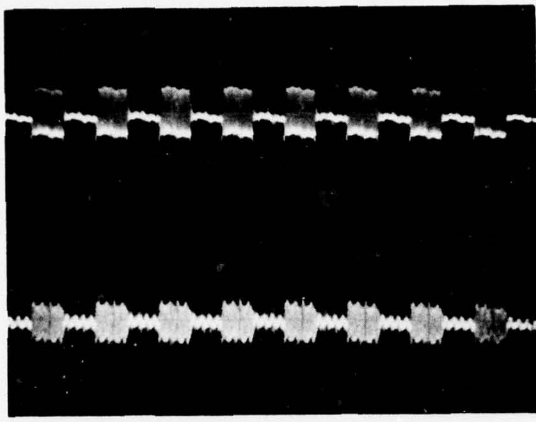
Denotes Specific Limits

Sweep speed: 5 ms/cm

FIGURE 5-30

WAVEFORM FOR THE -140-Vdc REFERENCE AT THE 096 UNIT (OPERATING MODE: VISUAL IDENTIFICATION)

Direct Oscilloscope Recording in Aircraft S.N. 500



-50 Vdc (Transistor)

P/N 464096 Unit

Amplitude: 100 mV/cm

+50 Vdc (Transistor)

P/N 464096 Unit

Amplitude: 100 mV/cm

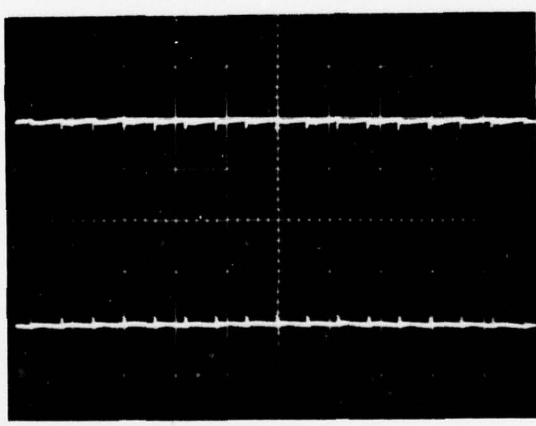
Note: Spikes to 300 mV peak-to-peak were present but are not visible on photograph.

Sweep speed: 2 ms/cm

FIGURE 5-31

NOISE PRESENT IN THE -50-Vdc AND +50-Vdc DISTRIBUTION AT THE 096 UNIT (DEFECTIVE 326 UNIT IN USE)

Direct Oscilloscope Recording in Maintenance Shop



-50 Vdc, No Load

P/N 464326 Unit

Amplitude: 100 mV/cm

+50 Vdc No Load

P/N 464326 Unit

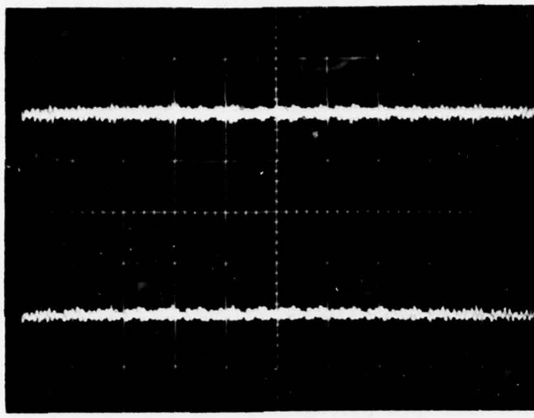
Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-32

NOISE PRESENT IN THE -50-Vdc AND +50-Vdc DISTRIBUTION AT THE 096 UNIT (SERVICEABLE 326 UNIT IN USE)

Direct Oscilloscope Recording in Maintenance Shop



-50 Vdc, No Load
P/N 464326 Unit (Defective Unit)
Amplitude: 100 mV/cm

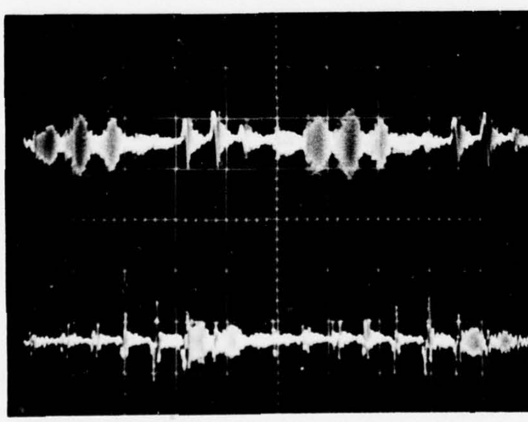
+50 Vdc, No Load
P/N 464326 Unit (Defective Unit)
Amplitude: 100 mv/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-33

NOISE PRESENT IN THE -50 Vdc AND +5-Vdc LINES

Direct Oscilloscope Recording in Maintenance Shop



-50 Vdc 100% Load
P/N 464326 Unit (Defective Unit)
Amplitude: 100 mv/cm

+50 Vdc No Load
P/N 464326 Unit (Defective Unit)
Amplitude: 100 mv/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-34

NOISE PRESENT ON THE -50 Vdc AND THE +50-Vdc LINES

5.4.1.10 -15 Vdc [Maximum Allowable Ripple 100 Millivolts Peak to Peak (mV P-P)]. No problems were noted with the -15 Vdc voltage when it was observed in the aircraft (see Figure 5-35, lower trace).

The upper trace of Figure 5-26, taken in the radar-shop mock-up, shows the noise level to be 590 mV P-P, well over the 100 mV P-P specification.

5.4.2 Unit Problems

5.4.2.1 -250-Vdc Power Supply (P/N 464192) - One problem with the 192 unit is the need to select tubes (i.e., trying several tubes) during maintenance to obtain the proper output voltage. This is a unit deficiency since properly designed circuits are not so critical that replacement tubes have to be selected. The tube selection as required in this application is expensive, involves many man-hours, and requires extensive use of the AGE equipment.

No adjustments are incorporated in this unit. This is complicated by the fact that tubes and other components may change slightly with age. Most well designed power supplies contain limited adjustments that can compensate for slight aging of components or tubes.

Another problem of the 192 unit concerns the NE-68s (neon bulbs) used in the saturable-reactor and voltage-amplifier circuitry. These components change with time and are partly responsible for the tube-selection requirement. Also, oscillations in this unit have been found to be caused by a change of value in the NE-68s.

The operation of the NE-68 regulators have been found to vary over a wide range when the unit is adjusted in normal light (as in the shop) and then retested in total darkness (as in the aircraft).

Four samples were tested with the following results:

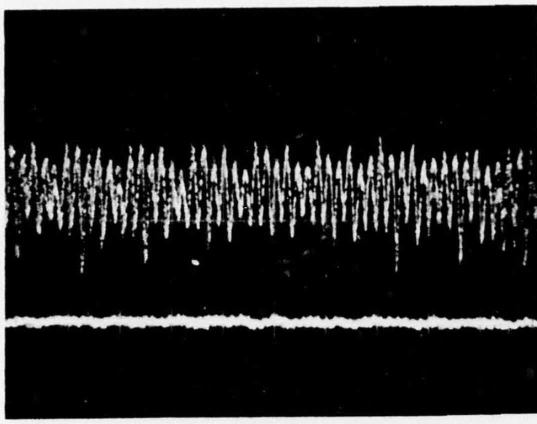
- Ionization voltage increased by 7 percent to 20 percent when the light source was removed.
- There was little change in the extinguish voltage or the operate voltage due to removal of the light source.

It is probable that units aligned in the shop's light would completely fail to regulate in the aircraft in the absence of light since the voltage required for initial ionization would never be reached.

5.4.2.2 +100V/-140V Reference Supply (P/N 464292) - No adjustments are provided in the 292 unit to compensate for component aging or difference in tube characteristics. This necessitates careful selection of replacement tubes.

Characteristics of the regulators are such that under specific load conditions or MA-1 system modes, high-amplitude oscillations occur. A square-type waveform of 2-milliseconds duration with amplitudes of approximately 3 volts were recorded and photographed.

Direct Oscilloscope Recording in Aircraft S.N. 500



+28 Vdc

P/N 464096 Unit

Amplitude: 500 mV/cm

-15 Vdc

P/N 464096 Unit

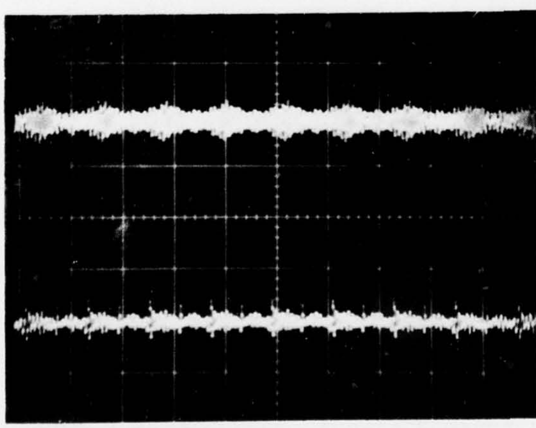
Amplitude: 100 mV/cm

Sweep speed: 2 ms/cm

FIGURE 5-35

WAVEFORMS OF THE +28-Vdc AND THE -15-Vdc DISTRIBUTION AT THE 096 UNIT

Direct Oscilloscope Recording in Maintenance Shop



-50 Vdc, No Load

P/N 464326 Unit (SN 37) Defective Unit

Electric Shop Mock-up

Amplitude: 100 mV/cm

+50 Vdc 100% Load

P/N 464326 Unit (S.N.37) Defective Unit

Electric Shop Mock-up

Amplitude: 100 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-36

NOISE PRESENT ON THE -50-Vdc AND THE +50-Vdc USING A DEFECTIVE 326 UNIT

The +100 and -140V reference voltages provided by this unit are utilized for precision bias and excitation voltages in the radar, FC&M, and computer subsystems and are extremely important to weapon-systems accuracy.

The vibrators (choppers) G1-G2 and G3-G4 must be matched (same manufacturer and part number); otherwise problems result. The polarity of chopper connections is reversed by one manufacturer (pins 3 and 4 or 1 and 6 are reversed). This in itself does not create a problem so long as two choppers of the same type are used for G1 and G2 or G3 and G4. However, the use of one manufacturer's chopper in G1 or G3 and a second manufacturer's chopper in G2 or G4 creates a problem because of the polarity of the pins. If the maintenance technician is not aware of this noninterchangeability, a unit might leave the shop with intermixed choppers. This would cause an on-aircraft computer malfunction.

5.4.2.3 <u>±50-Vdc and -15-Vdc Power Supply (P/N 464326)</u> - Power supply P/N 464326 contains two separate but identical channels. One channel develops and regulates the +50-Vdc power, and the other develops and regulates the -50 Vdc power. A divider network, consisting of a resistor and two series zener diodes connected between the -50 Vdc line and ground, develops -15 Vdc. Both +50 Vdc and -50 Vdc supplies contain a full-wave rectifier, a filter circuit, and two regulators. The input transformer is common to both supplies and operates on the 115-Vac, 1600-Hz, single-phase basic power. The regulators are controlled by magnetic amplifiers located between the input transformer and the rectifier.

One malfunction frequently attributed to the 326 unit is "stick chatter in the pilot-assist mode." During this program, voltage-output waveforms of +50 and -50 Vdc were observed in several 326 units in a bench mock-up at Dover AFB. Several units (operating satisfactorily) were observed under different load conditions and the waveforms were photographed (Figure 5-32) on one unit (Serial Number 348). No change was observed in the waveforms under the different load conditions. Next, a unit (Serial Number 37) that was removed from an aircraft "for stick chatter in the pilot-assist mode" was observed and photographed (Figure 5-33) under the same load conditions as the good unit.

In a good 326 unit (such as Serial Number 348) approximately 20 millivolts of noise (small spikes that occur at each half cycle of the 115 Vac, 1600-Hz voltage) are present on both +50 and -50 Vdc voltage outputs under no-load conditions (Figure 5-32). In the unit (Serial Number 37) removed from the aircraft, 40 millivolts of noise (at a higher frequency and not related to 115V 1600 Hz as it would be in a good unit) were present (Figure 5-33) on each output under no-load conditions -- approximately twice the normal noise exhibited by a good unit.

Next a 100-percent load was applied to the +50 Vdc output (no load on -50-Vdc output). There was no appreciable change in noise (Figure 5-32) on the good unit. However, on the unit removed from the aircraft the -50-Vdc output

(Figure 5-36, upper trace) increased to 80 millivolts, and the noise on the +50-Vdc output (Figure 5-36 lower trace) increased to 70 millivolts.

The 100-percent load was then applied to the -50-Vdc output (no load on the +50 Vdc), and waveforms were observed. No change occurred in the outputs of the good unit. The noise on the outputs of the unit removed from the aircraft changed to 140 millivolts (Figure 5-34, upper trace) on the -50-Vdc output and 150 millivolts on the +50 Vdc output (Figure 5-34, lower trace). All of the measurements are within the tolerance (200 millivolts peak to peak) specified in the checkout and troubleshooting procedures in T.O. 11F1-MA1-12-1, Section XVII, page 17-2.

The unit removed from the aircraft was repaired; a detailed record of repair actions was made. The malfunction was found in the -50 Vdc section of the unit. The large bursts seen in Figure 5-34 were attributed to a defective voltage comparator that consists of two encapsulated transistors. The spikes seen in Figure 5-34 were removed by replacing the voltage-amplifier transistor, Q10.

After the repairs were made, the +50 and -50-Vdc waveforms were observed to be the same as those observed for a good unit (Figure 5-32). These unit repairs corrected the stick-chatter malfunction. Testing this unit to the T.O. limits of 200 millivolts of noise on the +50 and -50 Vdc outputs would not have uncovered the malfunction.

Another item that may be affected by problems within the 326 unit is the new Multi-Mode Storage Tube (MMST) modification, which uses ±50 Vdc from this unit. The MMST appears to be sensitive to noise on the ±50-Vdc line. Also, several display tubes have been removed because of burn spots, and it is possible that these failures are related to the unit.

Other problems observed in the 326 unit are as follows:

- A common ground connection is not used; instead, brass ground studs are connected to the chassis. Corrosion has been observed at these connections, and in some cases the leakage of tantalum capacitors C6 and C25 appears to accelerate this corrosion.
- Resistors R14 and R29 are underrated, and they overheat.
- Oscillations occur under various load conditions when there is voltage imbalance in the voltage comparator Q1-A/B or Q6-A/B. This results in control-stick chatter in the pilot-assist mode of operation.
- The adjustments of variable resistors R8 and R23 must be set at their limit for proper output voltage. (ARINC Research recommended corrective action for this problem in the 20th Monthly Status Letter dated February 1966, Task RI-05-3).

AD-A054 705 ARINC RESEARCH CORP ANNAPOLIS MD F/G 9/3

RELIABILITY AND MAINTAINABILITY IMPROVEMENT PROGRAM FOR THE F-1--ETC(U)

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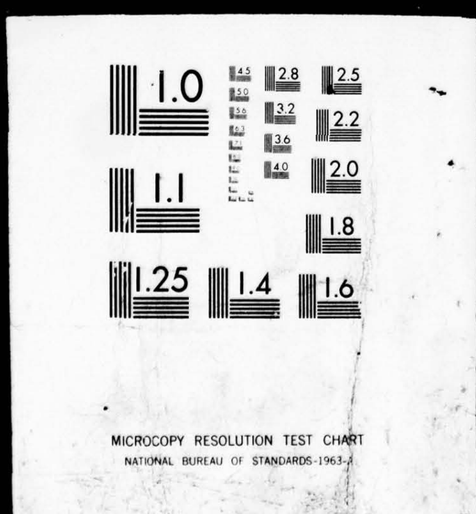


5.4.2.4 Units 464092, 464192, 464591, 464791, 464891, and 464991 - One of the major problems in the power subsystem is caused by the loop arrangement, whereby secondary power supplies and filter units are interrelated and dependent on other units for proper performance (see Figure 5-2). These conditions create feedback loops, which make it extremely difficult to pinpoint problems.

The 115-Vac, 1600-Hz source also provides inputs to this group of units, and supplies tube heater voltages and the power to compensate for under-voltage excursions in the related output voltages through the series clampax circuits.

A problem common to all these units is tube-type 6094 (clampax). These tubes frequently fail and go undetected in the aircraft when there is no T.O. requirement to check them during scheduled maintenance such as the 100-hour check. Failed tubes are not detected in the aircraft, because most tubes operate in parallel circuits; if one fails (from low omission, for example), the unit will still operate but in a degraded manner. One of these types of failure was observed during checkout of units removed from an aircraft. In this case a slow oscillation (see Figure 5-5) was observed on the +150 Vdc line, accompanied by slow recovery of the +150 Vdc under load switching (see Figure 5-19). This problem was corrected by replacing two type-6094 tubes in the P/N 464991 unit. One tube was removed for excessive leakage, and the other was gassy.

Provisions for testing tubes are made in shop procedures but not in any of the scheduled-maintenance procedures on the aircraft. Present flight-line noise checks do not disclose this type of malfunction. Testing of these tubes should be added to the 100-hour check to assist in detecting cases such as the one described above.

One other problem associated with power supplies and filter units was observed recently at Dover AFB. The type-6094 tubes had been replaced in one unit, but careful observations of the output revealed that the unit was still unstable. Further investigation revealed that the 100-ohm series equalizing resistor of one of the type-6094 tubes had changed value to 80 ohms. Replacement of the resistor corrected the malfunction.

5.4.2.5 Clock Pulse Generator, P/N 464489 - The clock pulse generator is not a part of the power subsystem, but this unit contains several voltage-test points such as the +100 Vdc reference. During tests of the Fault Detection Tester at Dover AFB, noise checks were made at TP-3 on this unit (the test point for +100 Vdc reference). However, this test was inconclusive, because a filter is located in unit 489 between the voltage source and TP-3. To obtain proper noise checks at this test point, the unit should be modified to provide a direct connection between the test point and the voltage source.

5.4.2.6 Units 464092, 464591, and 464791 - The series clampax circuits in units 092, 591, and 791, are designed to compensate for short-term low-voltage conditions that may occur in the -140, +150, and +300 Vdc circuits. The series

circuits are supplied by the 115-Vac,1600-Hz source. Parallel or shunt clampax circuits act to prevent the incoming voltages supplied by field regulator circuitry from falling below a specified minimum level. In this configuration, a momentary loss (less than 50 seconds) of the d-c source voltage from the field regulator units will cause the series clampax circuits to attempt to correct for this loss.

The series clampax circuit and transformer-rectifier supply (fed by 115-Vac, 1600-Hz source) were designed to correct for low-voltage conditions but become overloaded when required to withstand the full MA-1 system load. The normal result in this situation is an immediate catastrophic failure of components in the 115-Vac, 1600-Hz transformer and rectifier-filter circuits. A secondary result of this momentary condition is a short in the power transformer, which causes a power dump of the 115-Vac, 1600-Hz source and consequent loss of the entire power subsystem. The loss of the transformer, T-1, in unit 591 is typical of this type of failure, and transformer T-1 is known to be a high-failure item.

The addition of a properly designed overload-protection circuit would prevent aborts due to these short-term under-voltage conditions and prevent the catastrophic component failures that are now being experienced.

5.5 Findings Related to A-C Voltages

The basic a-c voltages generated for the MA-1 system are 115 volts, 3 phase, 400 Hz; and 115 volts, 1 phase, 1600 Hz. Frequency control of these voltages is dependent on the Convair frequency-control system. Voltage regulation of the 400-Hz and 1600-Hz sources is accomplished in the 892 unit (or in the interchangeable 992 unit) by controlling the field voltages of the 31056-002 MA-1 generator. The regulator circuits have a closed-loop configuration, with the sensing voltage being picked off the a-c power bus. Field power is derived from the output voltage except during initial turn-on, when the field is excited by 28 Vdc. The regulator units also contain circuitry to sense over- or undervoltage conditions and remove power from the MA-1 systems when these extremes occur.

When the system is being operated on the aircraft with ground power or in the system shop mock-up, the regulator sections of units 892 to 992 are not utilized. To test the condition of the complete field regulator unit in the aircraft installation, it is necessary to operate the system on aircraft-engine power. The electric-shop mock-up has provisions for connecting the test stand to an ECU-10 ground-power unit, to a short-life ground power unit (P/N 586-300), or to the motor-driven constant-speed-drive unit and aircraft-generator test stand. The short-life ground-power unit is configured with aircraft generators (P/N 464089) to permit shop maintenance of the field regulators. The constant-speed-drive unit is configured with aircraft generators of the same type currently in use on the aircraft. The major differences between the two generators are in the

28-Vdc section; however, there are also slight differences in field voltage and current requirements in the a-c section. These differences, noted during tests with a P/N 464892 regulator, were demonstrated by the fact that the voltage-adjustment controls required resetting to maintain the desired 116 volts during switching from the short-life ground-power unit to the constant-speed-drive unit.

The compatibility between shop test and aircraft installation conditions related to adjustment of the regulators could be enhanced by using the same type of generator in both locations. However, this will not completely solve the problem, because of differences in the voltage losses in the aircraft wiring. The Technical Order procedures call for a shop setting of 116 volts ±2 volts and a maximum deviation of 4 volts from a no-load to a full-load condition. Measurement of a-c voltages on an aircraft (using the 892 unit) following adjustment in the shop to Technical Order specifications results in a voltage reading approximately 2 volts lower than the shop setting. (The voltage difference is of less concern when the 992 unit is used, because this unit has wider control range.)

Investigation into the cause of the recorded voltage differences between the shop and aircraft installations indicated that additional voltage drop (IR loss) in the aircraft wiring and differences in regulator-sensing pick-off points were contributing factors. The a-c regulator is located some distance from the generator. In the case of the 1600-Hz supply -- which is a single-phase, two wire "floating" system -- a two-wire field supply is also required; this doubles the wiring losses. The wiring used from the regulator to the generator for the 1600-Hz field power is number 16 wire. The cable is approximately 35 feet long, for a total wire length of 70 feet. The full-load field current for this system is rated at 7.6 amperes. The IR loss for number 16 wire at 7.6 amperes was computed to be 30 millivolts per foot -- a total voltage drop of 2.1 volts rated generator load. The MA-1 system load is approximately 60 percent less than full rated load; therefore, the expected voltage drop in the aircraft would be 1.35 volts. This represents a major portion of the recorded 2-volt difference between shop and aircraft measurements.

The sensing-voltage pick-off point for the a-c regulators from the aircraft power bus is at the 162 unit. The current required by the sensing circuit is relatively small; the wiring is thus susceptible to noise and transient pick-up. The sensing-wire routing is not direct from the pick-off point to the regulator; it is routed to the P/N 174 rack through the 062 unit, back out through the P/N 174 rack and then to the P/N 074 rack, and eventually to the regulator unit.

An apparent design deficiency also exists. The pick-off points for the 792 and 692 units are made at about the midpoint of the sensing lines (P/N 174 rack). This practice of sharing the sensing lines with other circuitry, especially circuits of variable loading, is undesirable. The wire size between Terminal Board 16 and the 1600-Hz a-c bus is number 18, which is believed to be too small.

The result of this arrangement is amplitude modulation of the 115-volt, 1600-Hz MA-1 power during load changes on the 792 and 692 d-c regulators. Amplitude variations of the 1600-Hz supply were noted during this program. However, to measure and record properly the total effect of the sensing-lead loading and noise pick-up, it would be necessary to modify the aircraft wiring. This was not attempted during the program.

The 115-volt, 400-Hz system is a 3-phase, 4-wire "Y" connected system; the neutral point is connected to aircraft ground near the generator. The terminal strip for the MA-1 generator and the ground is located above the generator on the airframe. This area is subject to vibration. A number of cases of fluctuating 400-Hz MA-1 voltage were verified as loose ground connections at terminal strips TSN-6 and TSN-8. Access to the terminal-strip area with the engine installed is difficult. Therefore, it is desirable to check all connections on this terminal strip whenever the engine is removed.

The 115-volt, 1600-Hz reference voltage is developed in the 491 unit. It is derived from the 1600-Hz basic source and referenced to the +300 Vdc supply.

5.5.1 Voltage Problems

The a-c voltages of the power subsystem were observed and photographed in both the aircraft and shop environments. The conditions shown in the photographs taken on the aircraft represent an optimized F-106 power subsystem. Extensive work was performed on the subsystem in this aircraft in preparation for the field evaluation tests of the Fault Detection Tester.

The general findings concerning the various a-c voltages of the power subsystem are discussed in the following paragraphs. A later section covers the units associated with the a-c voltages.

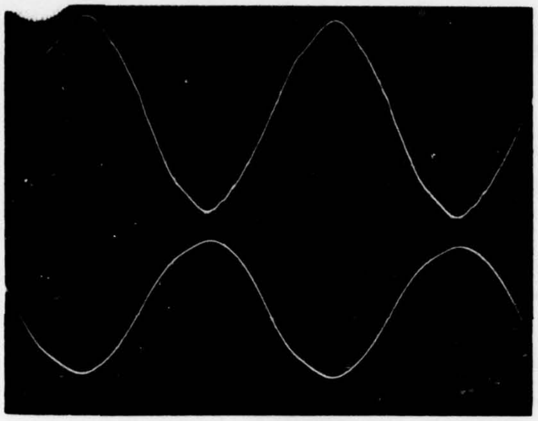
5.5.1.1 26 Vac, 400 Hz - The 26-Vac, 400-Hz, phase-B waveform as observed on the aircraft is shown in Figure 5-37. The 26-Vac return was photographed on the aircraft at the 289 unit and is shown in Figure 5-38. Note the presence of spikes with a peak-to-peak amplitude of 2 volts.

5.5.1.2 115 Volt, 400 Hz - Figure 5-39 shows the Phase-A waveform as it appears on a magnetic-tape recording taken in the aircraft. Figure 5-40 shows the waveform in the shop mock-up, taken from the magnetic-tape recording. The lower trace of Figure 5-41 shows Phase A as it appears in the radar shop mock-up with regulation provided by an AF/ECU-10M power unit.

The Phase-B waveform is shown in Figure 5-42 as it appears on a magnetic-tape recording on the aircraft. Figure 5-43 is from a magnetic tape run in the shop mock-up. The upper trace in Figure 5-41 shows Phase B as it appears in the radar shop mock-up with regulation provided by an AF/ECU-10M power unit.

Phase C is shown in Figure 5-44 as the waveform appears on a magnetic tape run on the aircraft. Figure 5-45 is from a magnetic tape run in the shop mock-up. The upper trace of Figure 5-46 shows Phase C as it appears in the radar shop

Direct Oscilloscope Recording in Aircraft S.N. 500



26 Vac, 400 Hz, Phase B

P/N 464289

Amplitude: 20V/cm

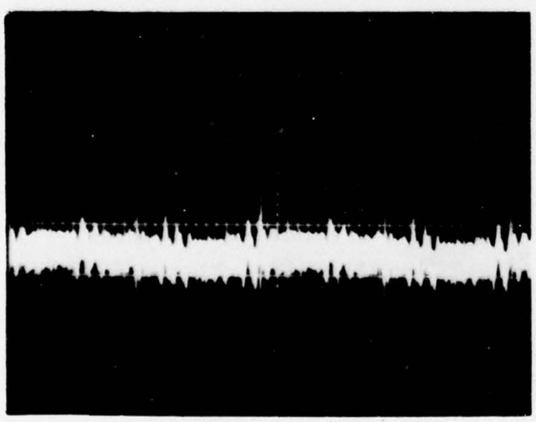
Note: Upper trace only.

Sweep speed: 0.5 ms/cm

FIGURE 5-37

26-Vdc WAVEFORM SUPPLIED TO THE 289 UNIT

Direct Oscilloscope Recording in Aircraft S.N. 500



26 Vac, Phase B (Return)

P/N 464289 Unit

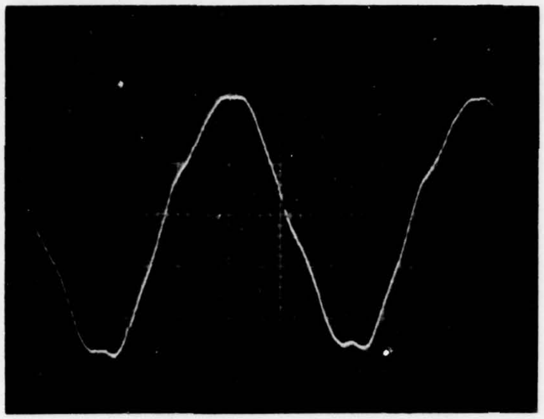
Amplitude: 500 mV/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-38

26-Vac RETURN LINE

Magnetic Tape Recording in Aircraft S.N. 500



115 Vac, 400 Hz, Phase A

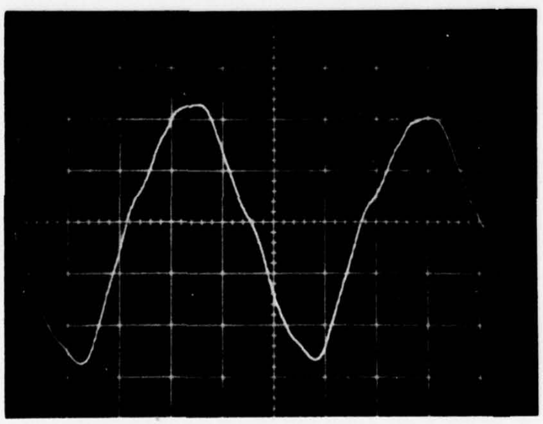
P/N 464489 Unit

Test Point TP-13

FIGURE 5-39

WAVEFORM FOR PHASE A, 400 Hz ON AIRCRAFT

Magnetic Tape Recording in Maintenance Shop



115 Vac, 400 Hz

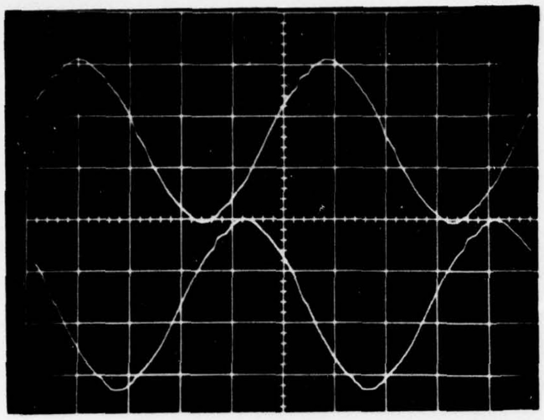
Phase A

Shop Test Stand

FIGURE 5-40

WAVEFORM FOR PHASE A, 400 Hz IN SHOP

Direct Oscilloscope Recording in Maintenance Shop



115 Vac, 400 Hz, Phase B
Radar Shop Mock-up Test Stand
Amplitude: 100 V/cm

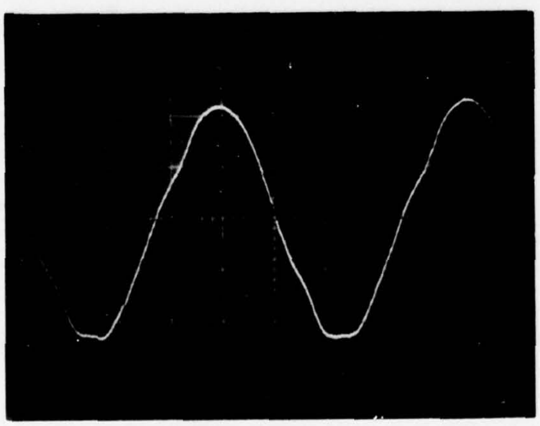
115 Vac, 400 Hz, Phase A
Radar Shop Mock-up Test Stand
Amplitude: 100 V/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-41

115 Vac AT RADAR TEST STAND

Magnetic Tape Recording in Aircraft S.N. 500

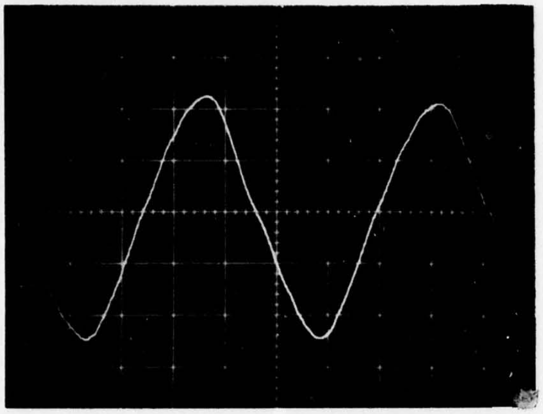


115 Vac, 400 Hz, Phase B
P/N 464489 Unit
Test Point TP-14

FIGURE 5-42

WAVEFORM FOR 400 Hz, PHASE B ON AIRCRAFT

Magnetic Tape Recording in Maintenance Shop



115 Vac, 400 Hz

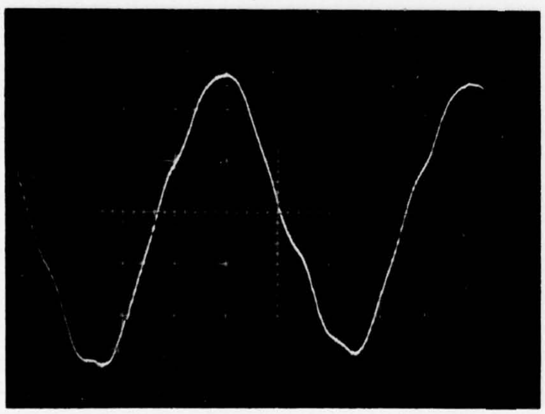
Phase B

Shop Test Stand

FIGURE 5-43

WAVEFORM FOR 400 Hz, PHASE C IN SHOP

Magnetic Tape Recording in Aircraft S.N. 500



115 Vac, 400 Hz

Phase C

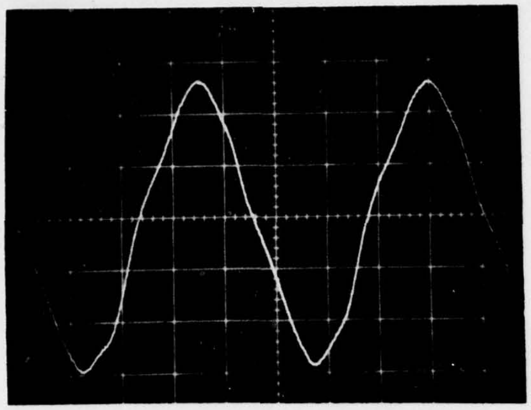
P/N 464489 Unit

Test Point TP-15

FIGURE 5-44

WAVEFORM FOR 400 Hz, PHASE C IN AIRCRAFT

Magnetic Tape Recording in Maintenance Shop



115 Vac, 400 Hz

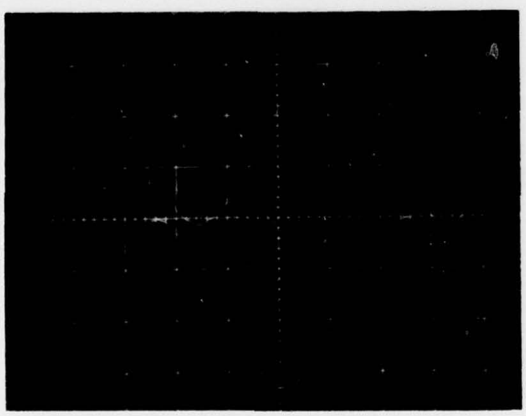
Phase C

Shop Test Stand

FIGURE 5-45

WAVEFORM FOR 400 Hz, PHASE C IN SHOP

Direct Oscilloscope Recordings in Maintenance Shop



115 Vac, 400 Hz, Phase C

Radar Shop Mock-up

Amplitude: 100 V/cm

115 Vac, 400 Hz, Phase A

Radar Shop Mock-up

Amplitude: 100 V/cm

Sweep speed: 0.5 ms/cm

FIGURE 5-46

115 Vac AT RADAR TEST STAND

mock-up with regulation provided by the AF/ECU-10M power unit. A phase-loading difference of approximately 15 percent exists between Phase A and Phase C for the 115-volt, 400-Hz source. A high-resistance connection from neutral to ground at the generator or terminal strip will therefore result in abnormal differences between phase voltages.

5.5.1.3 <u>55/115-Vac Reference</u> - The waveforms of the voltages as they appear in the aircraft are shown in Figure 5-47. Figure 5-48 shows the voltage waveforms as they appear in the radar shop. No changes in waveform were observed as a result of changing the loads by switching the radar.

5.5.1.4 <u>115 Vac, 1600 Hz Reference</u> - Two photographs, Figures 5-49 and 5-50, were taken of a magnetic-tape recording in the computer stand, they show a point where the peak-to-peak amplitude dropped to 150 volts for several cycles. Figure 5-51, taken in the radar shop, also shows this ripple.

Figure 5-52 shows the waveform as it was recorded by magnetic tape in the aircraft. Figure 5-53 is a photograph of a magnetic tape recording of the shop mock-up waveform.

5.5.1.5 <u>115 Vac, 1600 Hz Warm</u> - The upper trace of Figure 5-54 shows the voltage waveforms (regulation provided by the AF/ECU-10M power unit) with the radar transmitter turned off. Note the waveform distortion that occurs in the upper trace of Figure 5-55 (same point where Figure 5-54 was taken) when one radar transmitter is turned on:

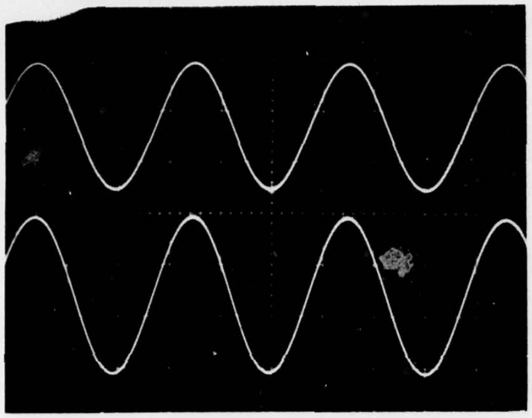
The 1600-Hz voltage waveform in a 326 unit, removed from an aircraft for control-stick chatter in the assist mode, is recorded in Figures 5-56 and 5-57. In this case the 326 unit was found to have oscillation problems; the results of these oscillations may be seen in the photographs.

5.5.1.6 <u>115 Vac, 1600 Hz Return</u> - The lower trace of Figure 5-54 shows the waveform, radar transmitter off, in the shop mock-up. However, with the transmitter on, harmonic distortion occurs, as shown in Figure 5-55.

5.5.2 <u>Unit Problems</u>

5.5.2.1 <u>P/N 464491 Reference Regulator Unit</u> - The 491 unit develops a 55/115 volt, 1600 Hz reference (to +300 Vdc) voltage for use by computer and radar resolver circuits. These circuits are extremely critical to both noise and out-of-tolerance levels. A review of maintenance history of the 491 unit disclosed that the most frequent complaint to result from failure of this unit was "computer stop". It was also found that this unit has both a high bench-check-serviceable rate and a high repeat-write-up rate. Investigation revealed that an unwanted 40- to 100-Hz modulation component was present in both serviceable and unserviceable units. Comparison tests of 491 units in the shop and in the

Direct Oscilloscope Recording in Aircraft S.N. 500



55-Vac, 1600-Hz Reference
P/N 464491 Unit
Amplitude: 20 V/cm

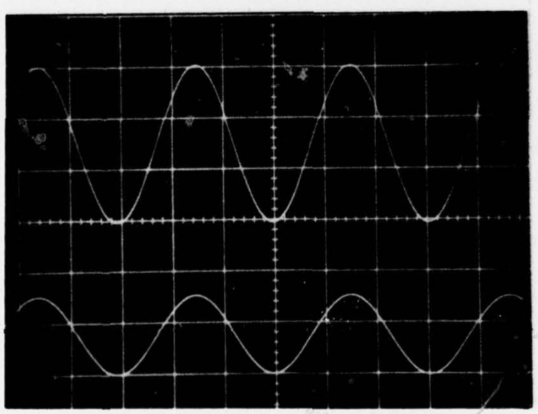
115-Vac, 1600-Hz Reference
P/N 464491 Unit
Amplitude: 50 V/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-47

A-C INPUTS TO THE 491 UNIT ON AIRCRAFT

Direct Oscilloscope Recording in Maintenance Shop



115-Vac, 1600-Hz Reference
Radar Shop Mock-up
Amplitude: 100 V/cm

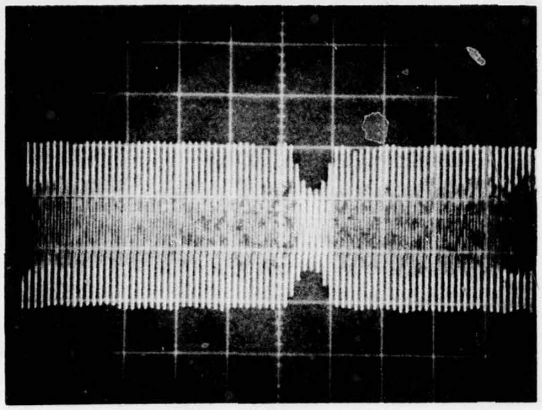
55-Vac, 1600-Hz Reference
Radar Shop Mock-up
Amplitude: 100 V/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-48

A-C INPUTS TO THE 491 UNIT IN SHOP

Magnetic Tape Recording in Maintenance Shop



115-Vac, 1600-Hz Reference

Computer Stand; 486101 Unit

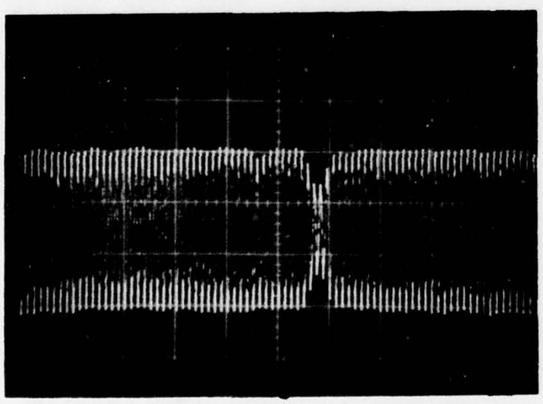
Amplitude: 100 V/cm

Sweep speed: 5 ms/cm

FIGURE 5-49

MODULATION OF 1600-Hz REFERENCE

Magnetic Tape Recording in Maintenance Shop



115-Vac, 1600-Hz Reference

Computer Stand; 486101 Unit

Recorder Monitored in Space
Normally occupied by the
P/N 464296 Unit

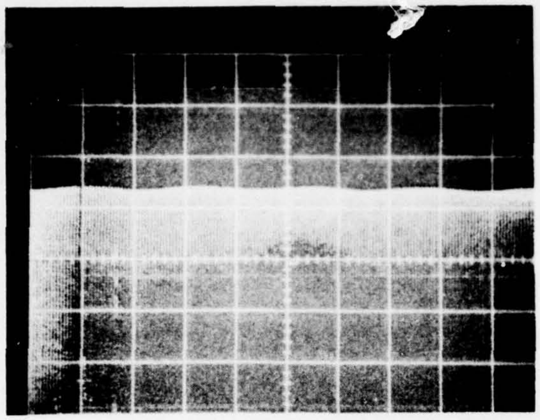
Amplitude: 100 V/cm

Sweep speed: 5 ms/cm

FIGURE 5-50

MODULATION OF 1600-Hz REFERENCE

Direct Oscilloscope Recording in Maintenance Shop



115-Vac, 1600-Hz Reference

Radar Shop

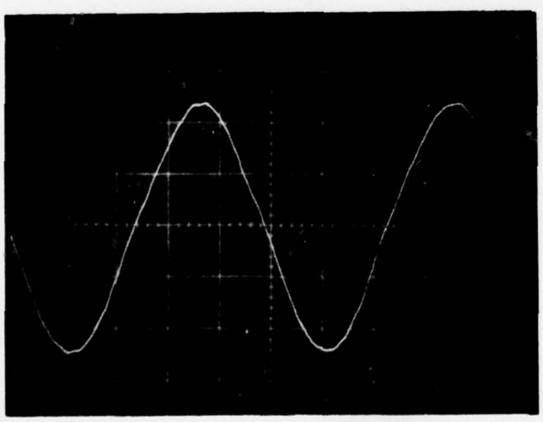
Amplitude: 20 V/cm

Sweep speed: 10 ms/cm

FIGURE 5-51

A-C RIPPLE ON 1600-Hz REFERENCE

Magnetic Tape Recording in Aircraft S.N. 500



115-Vac, 1600-Hz Reference

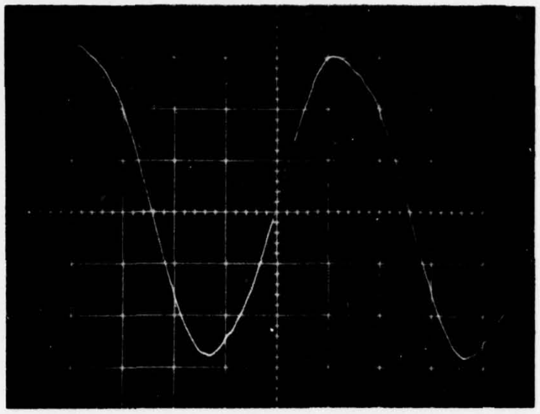
P/N 464489 Unit

Test Point TP-16

FIGURE 5-52

WAVEFORM FOR 1600-Hz REFERENCE IN AIRCRAFT

Magnetic Tape Recording in Maintenance Shop



115-Vac, 1600-Hz Reference

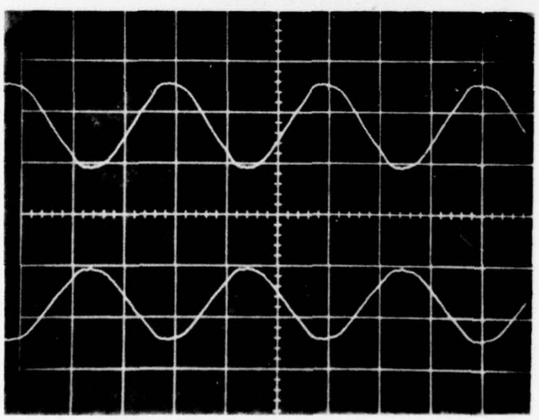
Shop Mock-up,

Test Point TP-16

FIGURE 5-53

WAVEFORM FOR 1600-Hz REFERENCE IN SHOP

Direct Oscilloscope Reloading in Maintenance Shop



Sweep speed: 0.2 ms/cm

115-Vac, 1600-Hz Warm Line

Radar Shop Mock-up

Amplitude: 100 V/cm

115-Vac, 1600-Hz Return Line

Radar Shop Mock-up

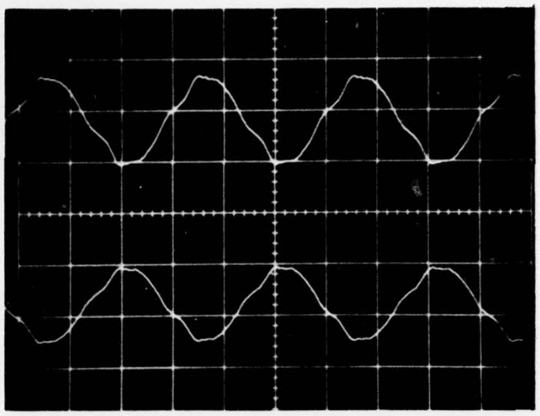
Amplitude: 100 V/cm

Radar Off

FIGURE 5-54

WARM AND RETURN LINES: RADAR OFF

Direct Oscilloscope Recording in Maintenance Shop



115-Vac, 1600-Hz Warm Line

Radar Shop Mock-up

Amplitude: 100 V/cm

115 Vac, 1600 Hz Return Line

Radar Shop Mock-up

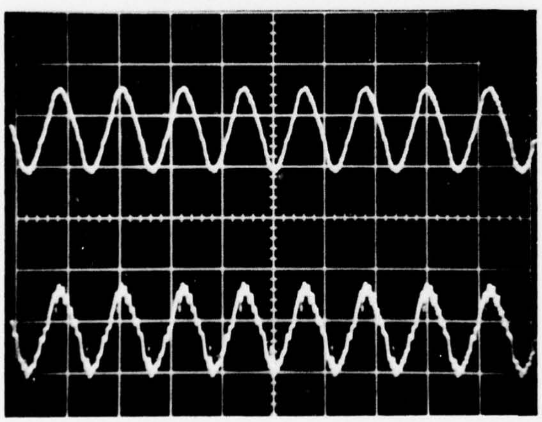
Amplitude: 100 V/cm

Sweep speed: 0.2 ms/cm

FIGURE 5-55

WARM AND RETURN LINES: RADAR ON

Direct Oscilloscope Recording in Maintenance Shop



115 Vac, 1600 Hz

P/N 464326 Unit, Pin 1-FL1

Amplitude: 100 V/cm

115 Vac, 1600 Hz

P/N 464326 Unit, Input at T1, Pin 3-FL1

Amplitude: 100 V/cm

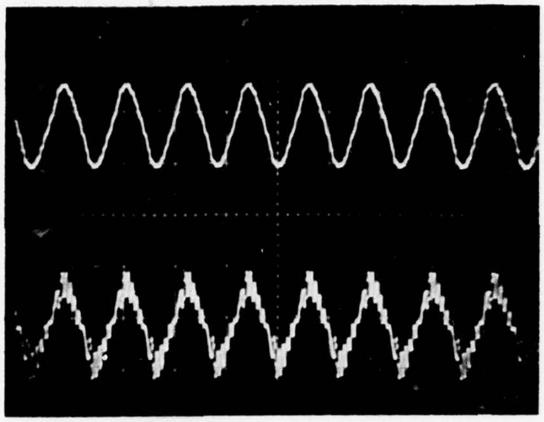
Note: No Load on ±50 Vdc outputs.

Sweep speed: 0.5 ms/cm

FIGURE 5-56

DISTORTION ON 1600-Hz LINE

Direct Oscilloscope Recording in Maintenance Shop



115 Vac, 1600 Hz

P/N 464326 Unit, Pin 1, FL1

Amplitude: 100 V/cm

115 Vac, 1600 Hz

P/N 464326 Unit, Input at T1, Pin 3-FL1

Amplitude: 100 V/cm

Note: 100% load on -50 Vdc outputs; no load on +50 Vdc outputs.

Sweep speed: 0.5 ms/cm

FIGURE 5-57

DISTORTION ON 1600-Hz LINE

aircraft indicate that the aircraft equipment will tolerate the presence of a modulation amplitude of one volt or less. Units with a modulation level in excess of one volt would not perform properly in the aircraft.

A number of the units that failed to operate in the aircraft were made usable by replacement of the magnetic amplifiers (AR1 and AR2). This did not eliminate the problem of modulation but reduced it to an aircraft-acceptable level. However, reducing the modulation amplitude to an acceptable level is not considered to be the solution to the problem, although it has reduced the unit repeat-write-up rate and increased the number of available, useable 491 units at Dover AFB.

To eliminate the problem it will be necessary to perform a complete analysis of the associated circuitry to define the combination of components and conditions that are the cause of the problem.

5.5.2.2 <u>P/N 464892 Unit</u> - A test was conducted by ARINC Research engineers at Dover AFB to compare the regulation characteristics of the P/N 464892 unit and the P/N 464992 unit. Two units of each type were tested on the LS-440 load bank using a 056 generator with a constant speed drive as the source and a T-121 digital meter to monitor the output levels. The test results, presented in Table 5-6, show that the two 892 units tested did not perform as well as the two 992 units, and support frequent reports of the poor regulation characteristics of the 892 units. An in-flight test of the 892 unit using the recording equipment was requested near the end of the contract period by SAAMA. Time constraints and limited aircraft availability made it impossible to perform this test.

TABLE 5-6 COMPARISON OF REGULATED VOLTAGES										
Unit	0% Load		25% Load		50% Load		75% Load		100% Load	
	400 Hz	1600 Hz	400 Hz	1600 Hz	400 Hz	1600 Hz	400 Hz	1600 Hz	400 Hz	1600 Hz
464892										
S/N 21147	117.0	116.0	116.5	114.0	115.0	112.0	113.8	110.0	112.5	109.0
S/N 23055	116.5	115.5	115.0	113.5	112.9	112.3	111.5	111.0	110.5	109.8
464992										
S/N 193	116.5	116.5	115.2	115.5	114.2	114.5	113.7	113.2	113.0	113.0
S/N 204	116.5	116.5	115.3	115.5	114.4	114.5	113.5	113.5	112.7	113.0

For test purposes several 892 units were adjusted to the proper regulation level in the shop, installed in an aircraft and rechecked. In general, the level dropped from the shop setting of 116 volts to 115 volts. This one-volt change alone would have little or no impact on the power subsystem. However, this variation added to the poor regulation capabilities of the 892 unit frequently results in a system malfunction due to low voltage. The 892 units that have been removed from an aircraft as a result of a low voltage problem have been successfully reinstalled and used by adjusting for regulation levels of 117 volts as opposed to the prescribed levels of 116 volts. This test demonstrates the significance of a small difference between the test operation and actual flight. A change in the test configuration, a change in the shop regulation level, or the addition of an on-aircraft adjustment capability would greatly improve this situation.

5.5.2.3 <u>P/N 464992 Regulator Unit</u> - The most frequent operator complaint associated with the 992 unit is an out-of-tolerance voltage condition. This condition is normally caused by variation in component operating characteristics due to aging. Problems of this type are corrected by component substitution, since this unit has no provisions for adjustment. The addition of adjustment capability would reduce maintenance time, the number of parts replaced, and the number of units returned to the special repair activity.

5.5.3 Effects of Harmonics on the 289 Unit

The Stable Element, P/N 464289, in the F-106 aircraft exhibited a high failure rate during the course of the ARINC Research investigations under Contracts AF09(603)-48024, AF09(603)-60655, and F09(603)67-A-0003-0001. This difficulty was aggravated by the 289-unit repair limitations. The rate of arrival of repairable units exceeded the rate of repair at the WRAMA SRA, resulting in a permanent overhaul and repair backlog.

To improve these conditions a number of tasks were initiated by WRAMA. One task assigned to ARINC Research was to define the possible effects of power deviations, particularly harmonics, on the reliability of the 289 unit. Information from Aircraft Power Specifications was correlated with the power actually experienced in a typical F-106.

Harmonic content specifications for aircraft systems have changed since the F-106 was designed. Changes to the aircraft electrical load have also taken place. Conclusions must therefore be based on what constitutes a reasonable amount of harmonic distortion for this power subsystem and this stable-reference equipment.

Military-Specification MIL-E-7894, 28 April 1952, was in force at the time of the original aircraft design. This was superseded by specification MIL-E-7894A, 17 May 1955. The latter document was superseded by Military Standard MIL-STD-704, 6 October 1959, which was in turn superseded by MIL-STD-704A, 9 August 1966. That portion of each of the three documents that applies to harmonic distortion is quoted below:

(1) From MIL-E-7894A, 17 May 1955: "3.2.1.2.5 Waveform -- The phase voltage waveform shall be within the following limits:

  (a) Amplitude factor: 1.41 ± 0.14

  (b) Harmonic content: The value of any harmonic shall not exceed 5 percent of the fundamental."

(2) From MIL-STD-704, 6 October 1959: "5.1.3.5 Waveform -- The voltage waveform shall be within the following limits:

  (a) Crest factor: 1.41 ± 0.1

  (b) Total harmonic content: 4 percent of the fundamental (rms) with linear loads, or 5 percent of the fundamental (rms) with non-linear loads, when measured with a distortion meter as distortion of the fundamental frequency.

  (c) Individual harmonic content: 3 percent of the fundamental (rms) with linear loads, or 4 percent of the fundamental with non-linear loads, when measured with a harmonic analyzer."

(3) From MIL-STD-704A, 9 August 1966: "5.1.3.5 Waveform -- The voltage waveform shall be within the following limits:

  (a) Crest Factor: 1.41 + 0.15 (see 7.6.8) (7.6.8 Crest Factor. The Crest Factor limits specified in this standard assume that the crest factor limits at the terminal of electric power sources do not exceed 1.41 ± 0.10 and are degraded to 1.41 ± 0.15 by the character of the loads.)

(b) Total Harmonic Content: 8 percent of the fundamental (rms) when measured with a distortion meter as distortion of the fundamental frequency.

(c) Individual Harmonic Content: 5 percent of the fundamental (rms) when measured with a harmonic analyzer.

(d) Deviation Factor: In any event, the waveform shall not deviate from corresponding points of the fundamental by more than 5 percent of peak value of the fundamental."

Note: MIL-STD-704A has been in effect for one year. During that time there has been an increasing sentiment among electronic equipment manufacturers and users of airborne electronic equipment for a return to the more stringent requirements of MIL-STD-704.

The Military Specification and the two Military Standards indicate that the harmonic distortion in the F-106 aircraft should not exceed five percent. In addition, Kearfott Test Instruction E-1220, supplied by the equipment manufacturer, Kearfott Corp. (now Systems Division, Aerospace Group of General Precision Inc.), specifies that the a-c voltage waveform shall contain less than five-percent harmonic distortion. Power distortion below the indicated level should permit the Stable Element to perform within its accuracy specifications and should not degrade performance.

Four a-c power waveforms were photographed between the 409 unit and the 289 unit on Aircraft S/N 500, operating on ground power. These four waveforms were analyzed to establish the coefficients of the Fourier Series equation, which has the form:

$$y = f(x) = A_0 + A_1 \sin x + B_1 \cos x + A_2 \sin 2x + B_2 \cos 2x + A_3 \sin 3x + B_3 \cos 3x + \ldots + A_n \sin nx + B_n \cos nx \quad (1)$$

From this general equation, the magnitudes of the coefficients allow quantification of the harmonic content in each waveform. The phase B' and C' power is used to drive the gyro spin motors. Phase A' is used in the same manner, but this bus also serves as the 400-Hz, 115-volt return, and it is the center point of the aircraft three-phase, four-wire "Y" generators. Figures 5-58 and 5-59 indicate the presence of some voltage distortion in phase B' and C' power. This distortion was defined as comprising odd-order harmonics. When the lower portion is superimposed on the upper portion, it is seen that the curves have symmertical positive and negative loops, excluding the possibility of even harmonics.

Figure 5-58 shows the phase B', 115-volt, 400-Hz power supplied from the 409 unit to the 289 unit at plug J28901, pin B. This photograph was reduced to a 35-millimeter slide and projected to approximately 20" by 25". Data points were

obtained from the projection, and a computer analysis of these resulted in the following Fourier Series equation:

$$y = f(x) = 115.00 \sin x + 0.79 \cos x - 0.26 \sin 3x - 0.11 \cos 3x \quad (2)$$
$$+ 2.99 \sin 5x - 0.77 \text{ cox } 5x - 1.39 \sin 7x + 0.98 \cos 7x$$
$$- 0.20 \sin 9x - 0.70 \cos 9x - 0.58 \sin 11x + 0.49 \cos 11x$$

The coefficent numbers are the rms voltage magnitudes of the components of the fundamental and the harmonics when the amplitude of the fundamental is 115 volts. This equation can also be expressed as only a sine function -- plus phase angle -- for the fundamental and each harmonic. In this case the equation becomes.

$$y = f(x) = 115.00 \sin (x + 0°24') + 0.28 \sin (3x + 203°02') \quad (3)$$
$$+ 3.18 \sin (5x + 345°32') + 1.59 \sin (7x + 144°58')$$
$$+ 0.73 \sin (9x + 254°29') + 0.75 \sin (11x + 139°52')$$

From Equation 3, each harmonic can be related as a percentage of the fundamental:

Third Harmonic	= 0.23%	Ninth Harmonic	= 0.63%
Fifth Harmonic	= 2.68%	Eleventh Harmonic	= 0.65%
Seventh Harmonic	= 1.47%		

Each of the harmonics is below 5 percent. The total harmonic content is defined as the rms value of the individual harmonics; it equals 3.2 percent.

Figure 5-59 is the phase C', 115-volt, 400-Hz power supplied from the 409 unit to the 289 unit at plug J28901, pin C. As in the previous case, a 35mm slide was projected and data points obtained. Computer analysis resulted in the following equation:

$$y = f(x) = 111.1 \sin x + 1.56 \cos x - 0.62 \sin 3x - 0.47 \text{ cox } 3x \quad (4)$$
$$- 2.59 \sin 5x - 1.10 \cos 5x - 2.14 \sin 7x - 0.59 \cos 7x$$
$$- 0.71 \sin 9x - 0.88 \text{ cox } 9x + 0.13 \sin 11x + 1.15 \text{ cox } 11x$$

Equation 3 expressed as sine function plus phase angle is:

$$y = f(x) = 115.00 \sin (x + 0°47') + 0.78 \sin (3x\ 217°14') \quad (5)$$
$$+ 2.28 \sin (5x + 336°58') + 2.22 \sin (7x + 185°26')$$
$$+ 1.12 \sin (9x + 308°55') + 1.15 \sin (11x + 96°28')$$

From Equation 4, each harmonic can be related as a percentage of the fundamental:

Third Harmonic	= 0.68%	Ninth Harmonic	= 0.98%
Fifth Harmonic	= 2.45%	Elevent Harmonic	= 1.0%
Seventh Harmonic	= 1.93%	Total Harmonic Distortion	= 3.3%

Each of the harmonics and the total distortion are, again, below the 5-percent level.

Figure 5-37 showed the voltage waveform for the 26-volt, 400-Hz input to the 289 unit. This voltage is developed from the aircraft 115-volt, 400 Hz, phase B through a step-down transformer in the 409 unit. This power is used in the 289 unit as the fixed field for the gimbal motors.

A 35mm slide of the waveform was projected; data points were obtained, and the computer analysis was performed. Careful examination of the waveform revealed that it does not have perfect symmetry about the horizontal axis (unequal positive and negative loops). Therefore, even-order harmonics do exist in the waveform. In this case the computer analysis resulted in a close approximation of the original curve (by including the first 15 harmonics).

Since all harmonics through the fifteenth are present in the waveform, and there are thus 30 terms in the solution, it is simpler to list the coefficients of the Fourier Series in tabular form than to write the actual equation. The coefficients for the sin nx and the cos nx terms, along with the distortion for each harmonic are shown in Table 5-7. The largest harmonic coefficient was found to have an amplitude of less than one-half volt. This represents just over two-percent distortion. The total distortion is the rms value of all harmonics; it equals 2.37 percent.

TABLE 5-7

PHASE-B VOLTAGE DISTORTION: 26 V, 400 Hz

Harmonic "n"	Coefficient sin nx "A_n"	Coefficient cos nx "B_n"	Distortion
1	26.00	0.185	------
2	-0.155	0.053	0.0065
3	-0.066	0.139	0.0059
4	0.045	0.083	0.0036
5	0.463	-0.254	0.0202
6	0.011	-0.002	0.0004
7	-0.120	-0.025	0.0047
8	-0.026	-0.087	0.0035
9	-0.041	0.075	0.0033
10	-0.063	0.023	0.0026
11	0.021	0.065	0.0026
12	-0.011	-0.029	0.0012
13	0.010	-0.042	0.0016
14	0.011	-0.007	0.0016

The 1600-Hz power is developed directly from the aircraft generator and is supplied to the stable element through the 409 unit. In the stable element it is supplied to the gyroscope heaters and accelerometers.

The 115-volt, 1600-Hz generator is arranged in the aircraft so that the center point is electrically at ground through the load. The 1600-Hz power is therefore carried by a twisted pair of shielded wires. One is designated the "signal" lead and the other the "return" lead (Figures 5-60 and 5-61). Although the total signal is 115 volts, the scope was referenced to aircraft ground and therefore shows 58 volts rms in each photo. The two waveforms closely resemble each other, and the five points of inflection near the maximum (and minimum) are of interest.

A 35mm slide of the waveform shown in Figure 5-60 was projected, and data points obtained for use in computer analysis. This wave is unsymmetrical about the horizontal axis and thus contains even-order harmonics. The fourier Series was developed through the twentieth harmonic, resulting in a close approximation of the original waveform. Table 5-8 lists of the coefficients of the Fourier Series for each harmonic and indicates the relative distortion.

TABLE 5-8

RELATIVE DISTORTION: 115 V, 1600 Hz

Harmonic	Coefficient sin nx "A_n"	Coefficient cox nx "B_n"	Distortion
1	115.00	-4.87	--
2	-0.262	0.128	.0025
3	-7.840	1.290	.0680
4	-0.220	0.094	.0024
5	-1.408	3.810	.0353
6	-0.422	0.107	.0038
7	-1.290	-0.645	.0125
8	-0.290	0.023	.0025
9	-0.045	-0.428	.0037
10	-0.084	0.247	.0023
11	0.128	0.168	.0018
12	-0.049	-0.066	.0007
13	0.107	-0.066	.0009
14	-0.090	-0.121	.0013
15	-0.565	0.276	.0055
16	0.126	0.275	.0026
17	-0.034	0.212	.0019
18	-0.187	-0.746	.0067
19	-0.183	-0.169	.0022
20	0.186	0.568	.0052

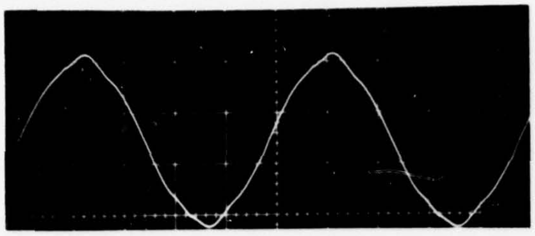


FIGURE 5-58

PHASE-B' WAVEFORM

115 V, 400 Hz
Plug J28901, Pin B
Voltage: 100 V/cm
Time: 0.5 ms/cm

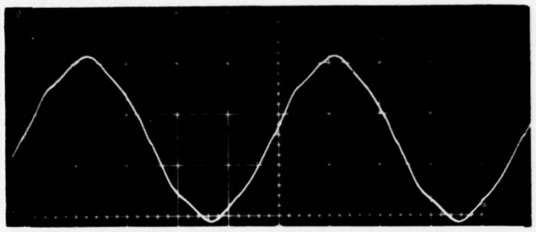


FIGURE 5-59

PHASE-C' WAVEFORM

115 V, 400 Hz
Plug J28901, Pin C
Voltage: 100 V/cm
Time: 0.5 ms/cm

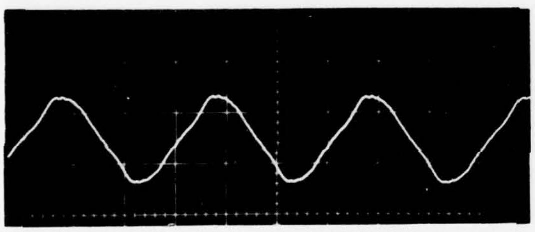


FIGURE 5-60

SIGNAL WAVEFORM

115 V, 1600 Hz
Plug J28901, Pin Z
Voltage: 100 V/cm
Time: 0.2 ms/cm

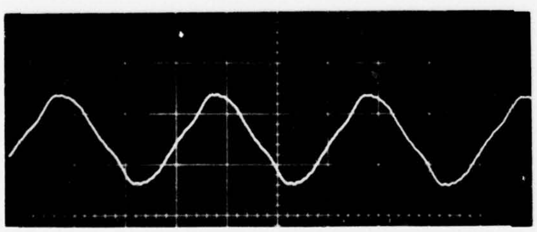


FIGURE 5-61

RETURN WAVEFORM

115 V, 1600 Hz
Plug J28901, Pin U
Voltage: 100 V/cm
Time: 0.2 ms/cm

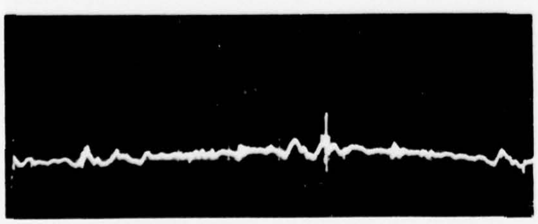


FIGURE 5-62

PHASE-A' WAVEFORM

115 V, 400 Hz
Voltage: 1 V/cm
Time: 0.2 ms/cm

Table 5-8 shows that the third, fifth, and seventh harmonics represent the major contributors to the total distortion, each being greater than one percent. The total harmonic distortion for this curve equals 7.88 percent.

To verify the analysis, tests were conducted on the system mock-up in the A&E shop at Dover Air Force Base. The three-phase, 115-volt, 400-Hz power for the system mock-up was monitored on a Tektronix Model 564 oscilloscope and a Hewlett Packard Model 330D distortion analyzer. The waveforms appeared to contain slightly less distortion than those used to perform the analysis. Measurements were taken while the generator was at minimum load and also while the UHF and computer subsystems were applied as loads. The results of total harmonic distortion are recorded in Table 5-9. These results are in close agreement with those of the waveform analysis conducted during this program.

TABLE 5-9

TOTAL HARMONIC DISTORTION

Signal 115 V, 400 Hz	Harmonic Distortion (%)	
	No Load	UHF and Computer Load
Phase A	2.4	3.2
Phase B	2.0	2.4
Phase C	2.6	3.2

Additionally, both lines of the 1600-Hz, 115-volt signal were monitored at two points in the mock-up. The total harmonic distortion at the input to the stable element was found to be 3.8 percent on the signal side at plug J28901, pin Z, and 3.5 percent on the return line at plug J28901, pin U. At the power jacks to the mock-up, the 1600-Hz signal read 4.6 percent total harmonic distortion on the signal side and 3.9 percent on the return line. Following these measurements, the radar equipment was turned off, and the distortion level at the signal jack to the mock-up was reduced to 4.1 percent.

All measurements taken on the system mock-up were below the established level of five percent. In-flight recordings were made of the aircraft power on 14 August 1967. The flight altitude was 12,000 feet, and the mission profile was Radar Lead Collision. The mission was recorded on Code 1 (no malfunctions, and no maintenance required.)

The 115-volt, 400-Hz power was recorded at the 489 unit. Figures 5-63, 5-64, and 5-65 show the phase A, B, and C waveforms as recorded. Visual inspection of these waveforms indicates that they are no worse than those analyzed earlier in this report. However, a peak-to-peak amplitude variation was present, and these amplitude variations prevent Fourier Analysis since the waveforms are nonperiodic. The worst amplitude variation recorded was approximately 10 percent, as shown in Figure 5-66 (Phase C).

The 1600-Hz, 115-volt unregulated waveforms for the signal side and the return line are shown in Figures 5-67 and 5-68. The high levels of distortion

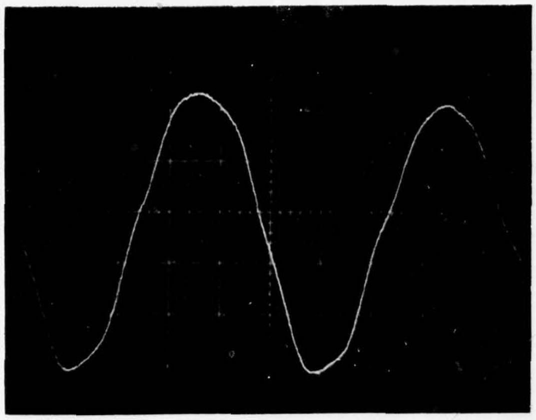


FIGURE 5-63

HARMONIC DISTORTION: AIRCRAFT PHASE A

115 Volts, 400 Hz

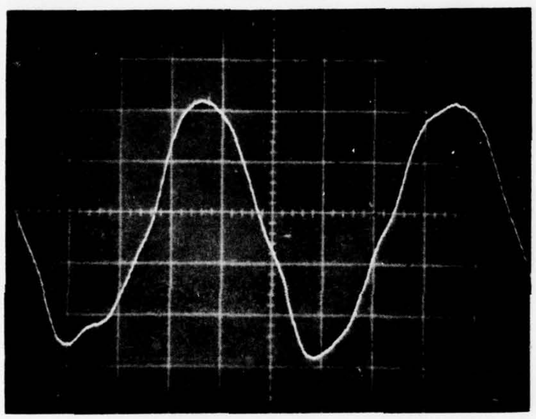


FIGURE 5-64

HARMONIC DISTORTION: AIRCRAFT PHASE B

115 Volts, 400 Hz

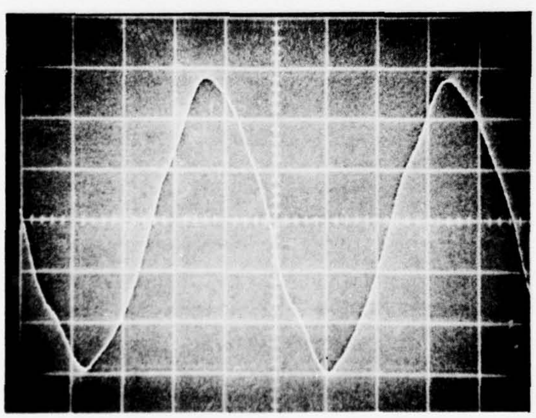


FIGURE 6-65

HARMONIC DISTORTION: AIRCRAFT PHASE C

115 Volts, 400 Hz

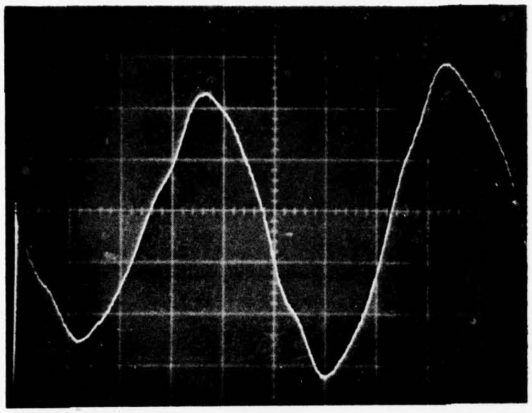


FIGURE 5-66

HARMONIC DISTORTION: AIRCRAFT PHASE C
(WORST CASE OF AMPLITUDE VARIATION)

115 Volts, 400 Hz

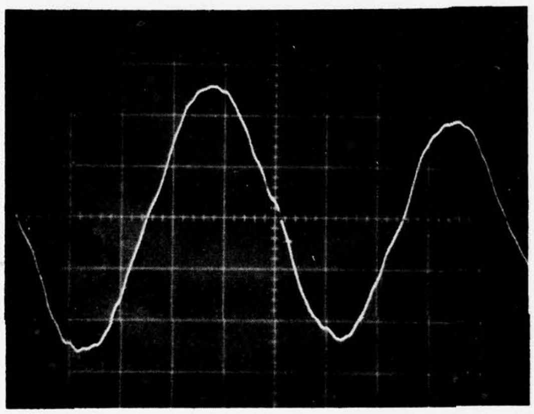


FIGURE 5-67

HARMONIC DISTORTION:
AIRCRAFT UNREGULATED SIGNAL SIDE

115 Volts, 1600 Hz

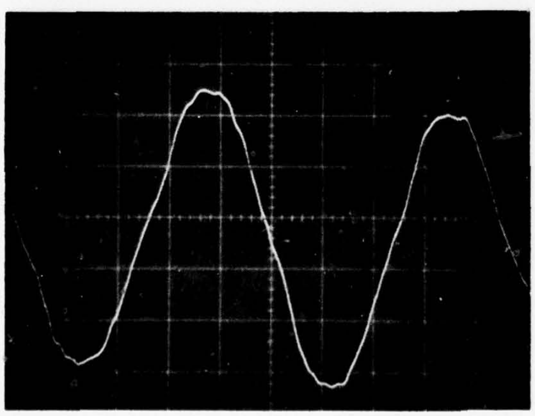


FIGURE 5-68

HARMONIC DISTORTION:
AIRCRAFT UNREGULATED RETURN LINE

115 Volts, 1600 Hz

discussed earlier (Figures 5-60 and 5-61) did not occur during the in-flight recording; however, amplitude variations were present.

The three-phase, 115-volt, 400-Hz aircraft power was monitored on aircraft S/N 500 on 10 October 1967. The amplitude variations noted on aircraft S/N 502 (one of serial aircraft instrumented) in flight were not present on aircraft S/N 500. Photographs of the aircraft power showed a typically small amount of harmonic distortion (less than 4 percent). The aircraft became unavailable for testing before a complete set of photographs could be obtained. Therefore, the absence of the amplitude variations cannot be documented.

The worst case of harmonic distortion recorded by photographic analysis or actual measurements was the 115-volt, 1600-Hz power experienced by aircraft S/N 500 while operating under ground power at Dover Air Force Base. Since this was the only incident in which harmonic distortion was found to exceed the five-percent limit specified in the Kearfott Test Instruction, it is concluded that this was a unique condition associated with one specific generator. The manufacturer's specification indicates that the equipment can be expected to perform without degradation on power being generated for the F-106 equipment.

The amplitude variation noted on aircraft S/N 502 is of concern. The three-phase, 400-Hz, 115-volt power is used in the 289 unit to power the gyroscope spin motors. It is assumed that these motors are of the synchronous type, and their speed is dependent only on input power frequency. Therefore, this amplitude variation should have no significant effect on the performance of the 289 unit.

The effect of the amplitude variation noted on the 1600-Hz power cannot be adequately determined, since the exact nature of the accelerometer and its circuitry are unknown at this time. However, these variations occurred on a flight that was scored as Code 1. In addition, the x- and y-axis signals are demodulated in the 209 unit and became a d-c level. It is therefore concluded that the accelerometer circuitry is insensitive to these variations.

5.6 Recommendations

ARINC Research recommends the following corrections to problems that have been discussed in some detail earlier in this section of the report:

(1) The clampax units (P/Ns 092, 591, 791, 891, and 991) should be added to the list of units to be checked during the 100-hour periodic inspection.

(2) A resistance check of the ground-strap connection should be added to the 100-hour periodic inspection. The total rack-to-airframe resistance should not exceed 0.01 ohms.

(3) A requirement to clean and tighten the generator field and output connectors and the connections to the associated terminal strip should be added to the major inspection procedures and to the routine associated with an engine removal or change.

(4) Replacing the 1600-Hz generator field wiring with a larger wire size should be considered.

(5) The sensing-voltage pickup point for the 1600-Hz regulator should be relocated to eliminate the requirement to share lines with the 692 and 792 generators.

(6) The Fault Detection Tester, Model MPM-54, should be used for noise-level tests on the power subsystem under actual on-aircraft operating conditions.

(7) Test points should be incorporated into the P/N 486111 power subsystem stand to provide for monitoring the generator field-voltage characteristics for all MA-1 generators.

(8) Availability of either the P/N 31056-002 and 464689-151 generator on the short-life ground-power unit or on the CSD-generator test stand for test and adjustment of the MA-1 field-voltage regulators should be assured.

(9) The remote-load bank (P/N LS-440) used with the power-subsystem test stand for regulator checks should be checked to verify that the desired load is being selected.

(10) The Technical Order procedures for maintenance and troubleshooting of the P/N 464992 a-c regulator unit should be updated and expanded to include in-circuit voltages and waveforms.

(11) Filter reactors (P/Ns 035 and 135) should be incorporated into the shop CSD-generator test stand to provide a more realistic generator test.

(12) The load-bank test capability, LS-440 and 486111, should be modified so that 100 percent load test of the 1600-Hz power is less than the present 63.0 amperes (or 60 percent more than the actual on-aircraft load). Preliminary findings indicate that a load corresponding to 75 percent of present test full load would be adequate. This change could be accomplished by a simple wiring modification in the load bank.

(13) A one-time test-inspection of all 035 and 135 units should be made. When all units are restored to the best possible condition, a preventative maintenance schedule to prevent degraded performance should be considered.

(14) A design review shall be undertaken for both the 892 and 992 units to stabilize the amplifier circuits. At the same time consideration should be given to relocating the voltage-adjustment controls, R2 and R20, to a front panel of the 892 unit.

(15) Maintenance personnel should be advised of the problems that can be caused by using a magnetic amplifier of varied characteristics (produced by different manufacturers) when repairing the 692, 792, and 892 units.

(16) A detailed investigation into the exact cause of the low-frequency oscillation and modulation that occurs in the 491 unit should be undertaken. Preliminary studies indicate a resonant condition that can be corrected with a minor change of component values.

(17) Adjustment provisions should be added to the 192 unit to compensate for component aging.

(18) The neon voltage-reference diodes, V13, V14, V15, and V16, should be replaced with suitable solid-state devices.

(19) The 192 unit should be modified to include decoupling circuitry in the -140-V bias-voltage input to the cathode of V11-B (pin 8).

(20) An adjustment should be added to the 292 unit to compensate for component aging and differences in tube characteristics.

(21) Maintenance personnel should be certain that the 292-unit vibrator units (G1- G2 and G3- G4) are used in matched-0 pairs from the same manufacturer and with the same part number.

(22) There is a design flaw in the voltage comparator and adjustment circuit of the 326 unit. It is recommended that, in addition to implementing the ARINC Research modification (Monthly Status Letter, February 1966), the following steps be taken:

- Resistors R14 and R29 should be replaced with resistors of similar value, but with higher wattage rating.
- Individual ground connections in the unit should be converted to one common ground point.
- Tantalum capacitors C6 and C12 should be replaced with new solid-state components to eliminate the present problems caused by leaking capacitors.
- The specified maximum-noise-level tolerance should be reduced from the present 200 mV to 50 mV for shop test of the unit.

(23) A modification of the 292 unit to connect the screen grids of V7 - V8 to the screen grids of V9 - V10 would reduce the oscillation tendencies resulting from unbalanced tubes.

(24) Shop tests of the 292 unit should include monitoring both output voltages simultaneously on a dual trace scope, while the technician switches loads to all other d-c supplies in the test stand.

(25) Front-panel adjustments should be provided on the 792 and 692 units to enable optimizing the output level in the aircraft.

(26) Adequate overload protection should be added to the 115 V, 1600-Hz input lines to the 092, 591, and 791 unit to prevent complete loss of the power subsystem and unnecessary component failures in the event of intermittent loss of the -140 or +300 Vdc generator power.

(27) Additional decoupling circuits should be added to certain bias lines to reduce the interactions now present. The lines are the +300 Vdc line in the 791 unit and the -140 Vdc line in the 092, 591, 891, and 991 units.

(28) Procedures should be expanded to provide additional in-circuit voltage data for the clampax units to enable maintenance personnel to better determine the conditions of the 6094 tubes in the regulators.

(29) The test-stand configuration should be changed to allow monitoring of unit test points without interaction with the basic voltage source.

Note: The maintenance personnel at Dover Air Force Base have, on their own initiative, implemented many of these recommendations (other than unit modifications) in a local test program. The results at the time of this writing are inconclusive; however, they are encouraging. Early in the test program it was noted that there was a major reduction in the rate of aircraft aborts due to power dumps. There were only one-fifth as many aborts due to power dump during the month after the program began than there were during the preceding month. And this trend is continuing well into the second month of the test. The gains to be expected from this reduction are numerous, with the most important one being the increase in the number of successful missions.

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6. HUMAN FACTORS

6.1 Introduction

The results of previous ARINC Research work had indicated that equipment performance is sometimes adversely affected by maintenance. For instance, it was found that up to 20 percent of the unreliability of certain electronic equipment installed in the B-58 aircraft could be attributed directly to previous maintenance activity rather than to the inherent unreliability of the hardware.*

WRAMA's reasoning that hardware performance (viz., reliability) is affected by the user and his maintenance procedures is supported by recent analyses of commercial aircraft electronics:

> "New data on avionic equipment failures indicate that the user and his maintenance procedures may have as great an effect on reliability as the manufacturer. This conclusion is based on widely different failure rates experienced by 21 airlines each using identical equipment. . . ."**

On the basis of analyses performed by ARINC Research in a previous contract,† WRNEW judged that equipment performance could be improved by modifying the maintenance situation. Accordingly, they established the following task:

> To develop modifications to procedures and techniques associated with the existing maintenance system, based on a detailed analysis of the problems associated with the existing system, and directed toward an overall improvement in maintenance efficiency and effectiveness.

The statement of the project task gave rise to three general questions, which served as guidelines throughout the study:

(1) To what degree does the maintenance system influence the effectiveness of the F-106 system as a whole?

(2) How is the influence exerted?

(3) How can the maintenance subsystem be modified to make the entire F-106 system more effective?

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*ARINC Research Publication 513-01-5-672, B-58 Aircraft Avionic Subsystems Reliability and Maintainability Program, October 1966.

**Philip J. Klass, "New Data Yield Clues to Reliability," Aviation Week and Space Technology, 17 February 1967.

† Final Engineering Report, Reliability and Maintainability Improvement Program for the F-106 Avionics, ARINC Research Publication 518-01-2-639, 19 July 1966.

Within the framework of these three critical questions, there were specific problems:

(1) How can the number of flights rated as successful be increased?

(2) How can the "bench-checked-OK" rate be reduced?

(3) How can aircraft availability be increased?

These problems are discussed in detail in Section 6.2.

Tasks were defined as follows:

(1) Data acquisition

(2) Data analysis

(3) Formulation of conclusions and recommendations

(4) Design for implementation and validation

Data elements were defined in terms of origin and use. Most of the required data were already at hand, as a result of previous and current ARINC Research work.

The data-acquisition effort is discussed in Section 6.3.

Data analysis was divided into two broad categories:

(1) Correlations between factors influencing total F-106 system effectiveness

(2) Analysis of maintenance-information system

Most of the quantitative analyses performed were of the first type.

The data analysis is described in detail in Section 6.4.

This study was concerned primarily with the problems of the F-106 maintenance system as it is now constituted. During the investigation, however, it was inevitable that investigators would encounter factors that influence the subsystem under study but appear to be external to it. These factors nevertheless contribute to total system effectiveness and therefore should be studied. On example of such a factor is the Fault Detection Tester, an item of test equipment that is currently undergoing final acceptance evaluation by the Air Force. Another example is the pressure for good performance (of both men and equipment), which influences maintenance reporting. These and other such factors are discussed in Section 6.5.

6.2 Problem Definition and Approach

6.2.1 Problems Defined in Terms of Objectives

6.2.1.1 Increase in Probability of Next-Flight Success

The probability of next-flight success in a given situation is the probability that the next flight following that situation will be rated successful by whatever criterion is used for determining success. This probability is determined by computing the percentage of following flights that are rated successful.

This definition of next-flight success contains two important concepts. First, there must be a specific criterion of success. It may be meaningful to call a flight a success even through the target was not successfully intercepted, if the radar functioned properly throughout the flight (i.e., the next-flight success probability of some subsystem can be treated separately from the next-flight success probability of the system as a whole).

Second, success can be examined as a function of the state of the system prior to flight (which gives rise to the name next-flight success). Thus, if the state of a system is determined by its previous flight, the probability of next-flight success is related to previous flight performance. In other words, a sequence of flights can be considered to be a Markov chain, with each transition probability determined by the current state.

The effects of maintenance on the transition probabilities of this Markov chain are not all clear. For instance, when maintenance involves the substitution of one or more components, is the system, in fact, still the same, with the same rules for determining transition probabilities? Because the number of possible states is large, an enormous number of observations would have to be made to determine a transition matrix. However, it is clear that next-flight success (according to whatever criteria are chosen) is a vital measure of system performance. First, as a measure of hardware performance, the probability of next-flight success for each subsystem is related to how well that subsystem is performing its function in the overall system, and is thus an important tool for the system analyst in determining overall system effectiveness and in analyzing possible improvements. Second, as a measure of maintenance performance, next-flight success as a function of maintenance state gives an indication of the effectiveness of maintenance.

The primary problem of this study, then, was: How can the probability of next-flight success be increased by means other than improving the intrinsic reliability of the equipment?

6.2.1.2 Decrease In "Bench-Checked OK" Rate

The second major problem confronted in the study was: How can the number of units "bench-checked OK" be reduced without (1) modifying test equipment, (2) degrading the spares supply, (3) reducing system reliability, or (4) significantly reducing system availability?

It is clear that what is sought is a way to reduce unnecessary shop work by reducing the number of "good" units processed through the shop. This reduction must be accomplished without performing trade-offs against equipment effectiveness. Furthermore, it has been demonstrated that the major cause of the high "bench-check OK" rate is the high rate of unit removals on the flight line, rather than faulty shop diagnosis. Thus the objective is to find a method of reducing the number of "good" units sent to the shop for maintenance without reducing equipment reliability.

Within the equipment-effectiveness constraint defined above, the following four areas can be explored to meet this objective.

(1) Can a flight-line maintenance strategy be devised that significantly reduces the total number of removals per repair action?

(2) Can a replacement strategy be devised in which good units are reinstalled in the aircraft, rather than being sent to the shop?

(3) Can the number of maintenance events in which no unit is removed be increased?

(4) Can the total number of maintenance events be reduced?

6.2.1.3 Increase in Total Aircraft Availability

Since the effectiveness of the F-106 system is directly proportional to its availability to fly against a target, an increase in its availability must result in a corresponding increase in its overall effectiveness. In addition to ensuring that the system will be in good operating condition when flown, it is also desirable to increase the fraction of "up" time (availability), time during which the system is available to be flown. The question to be answered, then, is:

Can the fraction of aircraft availability be increased without significantly increasing cost?

6.2.2 Problems Defined in Terms of Elements Studied

As well as defining problems in terms of objectives, it is possible to define them in terms of the elements studied. The basis for this study was the analysis of information transmission. It was found that the information system "rewards" some reports more than others (at least under certain circumstances), thus introducing bias into the information recorded. The emphasis is placed on what the system seems to reward when its content is used as a measure of personnel

performance, not directly on the "truth" of the data. The argument here is not that maintenance personnel do not tell the truth, but rather that they are placed in an environment in which telling the truth is at cross purposes with what the system rewards.

Analysis of information suggests the following questions:

(1) What is the effect of failure information on the performance of maintenance?

(2) What is the effect of the maintenance information system on the performance of maintenance?

6.2.3 General Assumptions Limiting Objectives

Certain assumptions were made that limited the objectives of this study, or at least provided guidelines within which the solutions to the problems were sought. The first assumption was that the quick-turn-around philosophy of flight-line maintenance is to be preserved. The F-106 electronics system is designed for "remove and replace" flight-line maintenance. Any changes in maintenance strategies must increase effectiveness of maintenance without reducing aircraft availability. The second assumption is that the objective should be primarily to increase operational-system effectiveness, rather than to concentrate on more efficient utilization of support-system manpower. Third it is assumed that recommendations for changes in maintenance strategy must consider the limits of the physical resources available (spare parts, equipment, and personnel).

6.3 Data Acquisition

This study was started with data already acquired by ARINC Research for previous work on the F-106 system. From the outset, it was known that certain data were missing. Therefore, a new data-acquisition effort was included in the early planning.

6.3.1 Previously Acquired Data

ARINC Research field engineers had acquired maintenance information on all maintenance events occurring during the period October 1965 to February 1966 at Dover Air Force Base and Selfridge Air Force Base. Table 6-1 lists all of the variables on which data were acquired and which this study considered. These data include: (1) a pilot identification code, (2) a coded description of what the pilot said was wrong, (3) a code for the maintenance supervisor (and also for his senior helper, at Dover), (4) a statement of whether the malfunction was verified, (5) an identification of which units were involved in the action, (6) a coded description of what the maintenance man said he found, and (7) an indication of the shop disposition of each unit.

TABLE 6-1
VARIABLES CONSIDERED IN FIRST DATA SAMPLE

Variable	Description or Explanation
Base	Dover, Selfridge
Squadron	71st, 94th, 95th FIS
Pilot Number	Locally assigned; not necessarily unique
Aircraft Number	Last three digits of serial number
Aircraft Report	Sequentially assigned by event within aircraft number
Date	Day, month, year
Cumulative Flight Hours	On this aircraft
Mission Type	Assigned Code*
Mission Success	Pilot's Rating of System Readiness: 1, 2, or 3
Mission Evaluation	Aborted (where) or other
Passes Attempted	Number of intercepts attempted during mission
Passes Completed	Number attempted minus number of symptoms reported
Report Type	Symptoms classified in 7 general areas
Reason for Report	Assigned code
Malfunction Number	Consecutively within aircraft report number
Symptom Code	From AFTO Form 76-3 as reported by ADCR-66-28 Code
When Discovered	Taken from AFM 66-1 codes
Severity of Complaint	ARINC Research field engineer's rating: 1, 2, 3, or 4
Verification of Complaint	Assigned code
Action Taken	From T.O. 1F-106-06 code
Maintenance Concept	Assigned code
Method of Troubleshooting	Assigned code
Next-Flight Success	Assigned code
AFCS Subsystem Downtime	Total maintenance delay time in tenths of an hour
Work Unit Code	From T.O. 1F-106-06 code for each unit involved
Flight-Line Action for Unit	Assigned code
Unit Serial Number	Last four digits of serial number
Unit Report Number	Consecutively within serial number
Unit Cumulative Hours	Estimated total operating hours
How Malfunctioned (Unit)	Symptom reported to shop on 210/211 form
Reason for Action (Unit)	Assigned code
When Discovered (Unit)	From T.O. 1F-106-06 code
Action Taken/Disposition (Unit)	Assigned Code
Method of Fault Isolation (Unit)	Assigned code
Unit Active Repair Time	Man-hours, for shop, in tenths of an hour
Flight-Line Personnel 1	Name code (Dover only) of maintenance supervisor for this action
Flight-Line Personnel 2	Name code (Dover only) of maintenance man No. 2 on this action
Squadron-Flight	A, B, or C according to work shift

*These codes, along with a detailed description of data-collection procedures, are presented in ARINC Research Publication 518-01-2-639 Reliability and Maintainability Improvement Program for F-106 Avionics (prepared for WRAMA, July 1966).

6.3.2 New-Data Acquisition

The new data were acquired at Dover Air Force Base for the period April to May 1967, with emphasis on the symptom report, verification report, action taken, and unit(s) replaced. These data were evaluated to determine whether the symptom was actually reproduced during maintenance, the action taken was appropriate, and the unit(s) installed could have corrected the malfunction as reported.

In addition to the hardware aspects of the maintenance reporting, ARINC Research desired information on the human influences in the reporting system. An attempt was made to isolate the factors that make some pilots better symptom reporters, since analysis had shown that the pilot was the greatest single factor contributing to next-flight success (see Section 6.4). Pilots were rated by debriefers according to cooperative spirit, ability to describe system malfunctions accurately, and willingness to assume responsiblity for pilot error. Pilots were rated "high", "medium", or "low" by six debriefers, and these ratings were converted into a numerical rating for each pilot.

6.4 Analysis of Data

6.4.1 Correlation of Factors Influencing System Effectiveness

Various factors that influence system effectivensss were believed to be related to each other. Statistical tests were performed to prove or disprove these hypotheses. The results obtained are described below.

The identity of the pilot was related to the number of symptoms reported after a mission. This relationship was established by a chi-square test on the distribution of number of symptoms by pilot identity. For pilots P_1, P_2, ..., P_i, ... P_n, the number of flights f_i was multiplied by the average number of symptoms reported per flight (by all pilots), and the resulting expected number of symptom reports ($\bar{n}_i$) was compared with the actual number (n_i) in a contingency table:

Pilot	P_1	P_2	...	P_n	
$\bar{n}_i$					
n_i					
$(\bar{n}_i - n_i)^2$					$\sum (\bar{n}_i - n_i)^2$

The hypothesis of independence of pilot identity and symptom frequency was rejected at the 0.01 significance level, indicating either that some pilots are reporting too many symptoms or that others are reporting too few. In either case, it is clear that symptom reporting is not uniform.

The specific symptoms reported were strongly related to the pilot; different pilots appear to concentrate on different symptoms. This fact was determined by an information analysis of the table of symptom vs. pilot:

Symptom \ Pilot	P_1	P_2	...	P_n
S_1	A_{11}	A_{12}		A_{1n}
S_2	A_{21}			
⋮			A_{ij}	
S_m				

$$X_1 = \sum_{j=1}^{n} A_{1j}$$

$$X_i = \sum_{j=1}^{n} A_{ij}$$

$$Y_1 = \sum_{i=1}^{m} A_{i1} \qquad Y_j = \sum_{i=1}^{m} A_{ij}$$

The amount of information in the distribution by symptom (X's) plus the amount of information in the distribution by pilot (Y's) minus the amount of information in the joint distribution (A's) gives the influence of the pilot on the symptom. This number divided by the amount of information in the distribution of symptoms gives the degree of influence exercised by the pilot. (For a full discussion of this method of analysis, see Final Engineering Report, Reliability and Maintainability Improvement Program for the F-106 Avionics, ARINC Research Publication 518-01-2-639.)

The identify of the pilot was found to be related to the probability of malfunction verification (at the 0.01 significance level).

The probability of malfunction verification is a function of the identity of the pilot who reported the symptom, more than of the symptom itself.

The pilot, the symptom reported, and the aircraft were all found to be related to next-flight success, with the greatest correlation being to the pilot.

Table 6-2 shows the relationship of several variables that were thought to be possible predictors of system performance and several proposed measures of performance. It is significant that the variable that has the greatest correlation with each of the measures is the pilot.

TABLE 6-2 PREDICTOR VARIABLES VERSUS SYSTEM PERFORMANCE			
Predictor Variable	Performance Measure		
	Total System Downtime	Malfunction Verification	Next-Mission Success
Pilot	35%	51%	29%
Symptom Reported	28%	30%	20%
Maintenance Man	29%	13%	9%
Aircraft Number	25%	24%	23%
Repaired Element	18%	N/A	12%

The percentage shown is that part of the variance in the criterion variable that can be accounted for by knowledge of the predictor variable. (Correlations between the predictor variables account for the fact that the sum of the individual predictor variances exceeds 100%.)

6.4.2 Analysis of Maintenance Actions

This study was focused primarily on maintenance effectiveness (probability of successful repair). However, efficiency (manpower, equipment, and time utilization) was not ignored. To reach conclusions regarding profitable allocation of effort, it was necessary to study the physical performance of maintenance.

6.4.3 Analysis of Pilot's Symptom Reporting

Debriefers' ratings of pilots were found to be related to symptom frequency and next-flight success, but the relationship was not obvious. This correlation can be useful only if the cause-effect mechanism can be discovered. The goal of future analysis in this area, then, should be to determine what makes some pilots better symptom reporters than others and how pilots can be trained to report better.

6.5 Peripheral Influences

There are peripheral influences, not properly part of the maintenance system, that have significant effects on motivation in the performance of the maintenance system. There are also items of equipment (or modifications to equipment) which are not now part of the system but which, when incorporated into the system, can have a significant effect on performance.

6.5.1 Unofficial Ratings

Throughout the Air Force, there are official rating systems: pilots are rated on performance of technical (piloting) skills and on various military characteristics; officers in supervisory positions are rated by criteria of supervisory effectiveness as well as military characteristics; enlisted men

at every level are rated by measures of performance. The pressure to achieve is certainly felt at every level.

In addition to these official ratings, other, unofficial ratings are being made all the time. Possibly, these should be properly called judgments, rather than ratings; however, each man is constantly being judged by both his peers and his superiors. When the pressures created by these judgments are at cross-purposes with the objectives of the system, then the system suffers. For example, when a maintenance man feels pressure to work fast, he may tend to judge reported malfunctions as "cleared" when in fact they are still present. A goal of supervisory personnel at all levels, then, should be to assure that pressures do not work against the interests of the system.

6.5.2 Outside Demands

An important influence on the performance and reporting of maintenance is the demands placed on the maintenance system (and on the F-106 system) by the Air Defense Command. The level of effort and the level of reported performance are related directly to those demanded by higher-command levels. Thus when a maintenance officer is told that he must have a certain level of availability, he makes sure that his records show aircraft availability to be as required. This may involve demanding more or better work from his men, or it may involve some data manipulation to shown an increase. It is this latter situation that may prove harmful. When information "fudging" is encouraged to meet some criteria for acceptable performance, something is wrong with the information system.

6.5.3 Spare-Parts Allocation

During this study it was learned that the spare-parts-allocation policy is actually working against the philosophy of remove-and-replace for quick turn-around. The number of spares of each part (or component) allotted to each installation is determined by the past history of failures of that part*. However, items that are "bench-checked OK" are not recorded as failures for purposes of spares allocation. Thus the fact that the unit was removed from the aircraft (requiring an immediate replacement) and processed by the shop (requring some unit downtime) is not accounted for in the allotment of spares of that unit type. The result of this policy is that maintenance personnel feel it necessary to report a discrepancy on each unit removed so that their future spares supply will be adequate for the remove-and-replace maintenance they must perform.

6.5.4 New Test Equipment

During the investigation, information was obtained on the Fault Detection Tester (FDT), a device used to test the functions of the MA-1 on the ground by

*Air Force Manual 67-1, Volume II, Chapter II, describes in detail the procedure for determining stock levels.

programmed simulated inputs and measurements of outputs. If the Fault Detection Tester proves itself to be reliable and practical to use, it will provide a check on the state of the system that will eliminate the need for the pilot in the information loop. This will not mean that pilot information will be completely ignored; however, the pilot may be influenced to report more accurately, knowing that he is subject to check by the FDT. Similarly, although the maintenance man will still have to verify the symptoms to repair the malfunctions, there will be more incentive for him to repair only the real malfunctions. This observation applies also, of course, to any other test equipment that provides symptom information.

6.6 Conclusions and Recommendations

In Section 6.2, three objectives were stated:

(1) An increase in the probability of next-flight success

(2) A decrease in "bench-checked-OKs"

(3) An increase in total aircraft availability

The following material answers the four questions raised in Section 6.2.1.2 with regard to these three objectives. Recommendations are made, and a plan for validating them is presented. Pilot/maintenance man motivation is also discussed.

6.6.1 Reduction of Number of Removals

Can a flight-line maintenance strategy be devised that significantly reduces the number of removals per repair action? It is ARINC Research's judgment that it is not possible to reduce significantly the number of removals per repair action within the other constraints imposed. Such reduction would require the following:

- Large increases in troubleshooting time
- Extensive revision of troubleshooting methods
- Many additional test equipments

This is not to say, however, that the total number of removals cannot be reduced (see below).

6.6.2 Replacement of Good Units

Can a replacement strategy be devised in which good units are reinstalled in the aircraft rather than sent to the shop? Such a strategy should make significant reductions in shop checks and at the same time increase system reliability. If several units are removed from an aircraft before the malfunction is cleared, those units not responsible for the malfunction should be reinstalled in the aircraft. This procedure would require little additional flight-line maintenance time. It would reduce the number of wasted shop checks by a large

fraction, and it would result in better system performance because of the greater degree of system integrity preserved.

6.6.3 Reduction of Repair Actions

Can the percentage of maintenance events in which no unit is removed be increased? Here it is necessary to distinguish between a repair action and a maintenance event. A maintenance event occurs whenever a maintenance man investigates a symptom report; a repair action occurs whenever a maintenance man attempts to correct a malfunction. It has been noted both by ARINC Research and by Air Force maintenance officers that the percentage of symptoms that are verified is much higher than might be expected. This high verification rate is due to excessive confidence in the symptom reports of the pilots, coupled with pressure on the maintenance man to "fix" the equipment following each symptom report. In general the pilots' symptom reports are not infallible, and the maintenance men should be encouraged to be completely objective, rather than "proficient". Of course, this approach may be different to implement, because of the problem of quantifying the aforementioned confidence in symptom reporting, but it can be recommended that symptoms which are reported as "intermittent" should not be pursued unless they are obviously verified or are repeat write-ups, or they affect the safety of flight. This would entail a change in maintenance philosophy in that management must be prepared to accept a larger number of repeat write-ups (other than safety).

6.6.4 Reduction of Maintenance Events

Can the total number of maintenance events be reduced? One approach to this problem is to increase the probability of next-flight success. Another approach is to reduce the number of spurious symptom reports. Through the institution of a team concept in the assignment of pilots, maintenance men, and aircraft, both of these improvements will be effected. First, the maintenance men will do better work because they will be more deeply involved in the performance of the aircraft. Second, the pilots will submit better reports because they will be more closely concerned with the performance of the maintenance men. Ideally, this team consist of one pilot, one crew chief, and one aircraft. However, operational constraints make this impractical. Nevertheless, the Air Force can approach this ideal by employing the smallest groups possible and minimizing the cross-assignments from group to group. This concept is discussed further below.

6.6.5 Delineation of Performance Goals

A possible solution to the problem of inaccurate symptom reporting by the pilot is to delineate clearly the objective of each flight. When a pilot is on a training flight, he should not be judged by the standards applied to evaluation flights. If most flights were considered training flights, pilots would not feel

the same pressure to perform or place the blame; there would be less emphasis on "blame." Likewise, the delineation of realistic goals for maintenance would tend to increase the effort spent on legitimate repair work, and decrease that expended on "cover up" work. Thus the maintenance man's objective should be to assure that the equipment is performing properly rather than to "clear a complaint."

6.6.6 Use of Test Equipment

The use of test equipment, in addition to aiding the maintenance man in troubleshooting and repair, can also serve as a motivation for the pilot and the maintenance man to report more accurately.

During this study, ARINC Research personnel visited Aircraft Armaments, Inc. (AAI), where they were briefed on that company's Fault Detection Tester (FDT). From a human-factors point of view, the equipment design is quite good. The displays are well arranged; controls are convenient; troubleshooting communication channels are quite effective. The primary concern regarding the implementation of the FDT as a useful aid to maintenance is its plausibility. If any test equipment is to be effective, the user must have confidence in it. During early acceptance tests at Dover AFB, the FDT has experienced reliability problems (such as power-supply failures) that may create lack of confidence in its capabilities, in which case its usefulness will be limited.

6.6.7 Validation of Recommendations

The steps recommended above lend themsleves readily to statistical validation. In a short test program, the efficacy of each recommendation can be tested.

6.6.7.1 Troubleshooting Strategies

The Air Force can verify that the expense of redeveloping the troubleshooting strategies for flight-line maintenance would far outweigh the benefits to be gained. The value of the improvement must be measured in terms of man-hours saved, plus the additional reliability to be achieved by making fewer changes in equipment integrity. ARINC Research believes that changes in the troubleshooting strategies could not significantly reduce the number of removals.

Appendix B describes a method for determining the optimum troubleshooting strategy for a particular symptom. The information required for this method includes the expected cost of checking each unit and the probability that, the given symptom, the unit is the malfunctioning one. Even under the assumption that unit checkout costs are equal, the information requirement for computing troubleshooting strategies is substantial. Under present conditions of manpower utilization, it does not seem worthwhile to expend the money and effort that would be required for a small improvement. Of course, this judgment is subject to review in the light of new analysis techniques or new requirements.

6.6.7.2 Replacement Strategy

The policy of reinstalling good units in the aircraft after the malfunctioning units have been identified would reduce shop time (which would be significantly greater than the extra time spent at the flight line) and would simultaneously result in better performance. The change in performance, as well as the time saving can be determined by a simple experiment. At a base where other conditions can be kept equal, the maintenance jobs are divided into two sets. One set is completed by substituting spares for all units removed from the planes. The other set is completed by reinstalling all good units in the aircraft after the faulty ones have been found. Then, with a large enough sample of maintenance actions to produce statistical significance, the following are determined:

- The extra cost, in man-hours, of the replacement strategy
- The saving in shop man-hours
- The change in reliability of the equipment worked on

6.6.7.3 Verification Requirements

The institution of more realistic criteria for verification and a more realistic attitude about symptom reports will significantly reduce the number of events in which units are removed. This is especially true for symptoms reported as "intermittent." This change would result in substantial savings of flight-line and shop time; it is also believed that it would not adversely affect equipment reliability. This conclusion could easily be verified by observing the next-flight success of *maintained* and unmaintained equipments following "intermittent" symptom reports. Some sample (random) of "intermittent" symptoms would be checked out with rigorous criteria, and if they were not verified, no maintenance would be performed. The observations would be easy to test by a chi-square test for significance in the following form:

Event	Number of Occurrences	Number of Next-Flight Failures
Intermittent failure not reproduced, but some repair action taken		
Intermittent failure not reproduced, no repair attempted		

6.6.7.4 Team Assignments

To validate the recommendation concerning team assignment of planes and men, such a system would be inaugurated for some of the men and planes at a base, while other assignments would be made on a random basis. At the end of the test period, the effectiveness of the two approaches would be compared according to the criteria of next-flight success, mission success, maintenance

man-hours, etc. It is crucial that this validation experiment be carried out in a situation in which the influence of other factors, such as mission type and flying conditions, will not affect the comparison.

7 SPECIAL TASKS

In this program WRAMA Engineering assigned five special tasks to ARINC Research. The results of these tasks were reported in detail to WRAMA in attachments to the Monthly Status Letters. They are summarized briefly below.

7.1 Evaluation of the General Electric Rapid Tune Test Set

7.1.1 Task Definition

ARINC Research was directed to evaluate the proposed General Electric Rapid Tune Test Set to define its advantages and disadvantages as compared with current test methods. A secondary consideration was to consider possible improvements through changes in the production model of the test set.

7.1.2 Task Summary

General Electric designed and constructed an engineering model of a test set for use in conjunction with the Rapid Tune Units (P/N's 464541, 464641, and 464741) of the F-106 radar system.

The test set was partially evaluated in an earlier test program by the Air Force. ARINC Research completed the evaluation by comparing the results obtained with the tester with those obtained through current test methods. Major considerations for the ARINC Research evaluation were the following:

- Impact on the operational system
- Compatibility with the system
- Test accuracy and fault-detection capability
- Tester reliability and maintainability

7.1.3 Conclusions

The proposed test set, with minor modifications as noted below, will generally fulfill the requirements for field-base repair and alignment of the three General Electric units (P/N's 464541, 464641, and 464741) employed in the post-Group II configuration of the F-106 MA-1 system.

Specific conclusions are as follows:

- The tester will greatly relieve the present work load on the Radar-IR test stand.
- Unit standardization will be significantly improved since each unit will be checked against a standard unit rather than against units in another system. This testing approach provides uniformity of performance through the elimination of interface variables.

- A greater degree of accuracy can be obtained with the GE tester because of its more accurate read-out.
- Test and alignment times are reduced through the use of the GE tester.
- Malfunctions or marginal operation that can reduce system performance but are not readily detectable through current methods are easily detected by use of the GE tester.

7.1.4 Recommendations

The following recommendations are made:

- The present method of providing additional cooling air to the 641 unit during test should be modified.
- The present method for mounting the 641 unit should be modified to allow 360° rotation of the unit for better maintenance access.
- Procedures should be instituted to permit use of the extender boards supplied with the test stand.
- The test cable used with the 541 unit should be lengthened.
- The necessary wiring should be installed and procedures instituted to permit measurement of Threshold No. 1 and No. 2 voltages, and to eliminate the present requirement for an external voltmeter.
- The module mounting screw in the tester should be changed to permit connector alignment prior to screw engagement.
- The procedures should be modified to ensure that the 741 unit will provide the proper filament voltage to the 641 unit in the aircraft. (A similar change may be required for the F-101/MG-13 system.)

7.2 Reliability Investigation of IFF Control Switch

7.2.1 Task Definition

WRAMA, WRNEW directed ARINC Research to investigate the failure of the control-switch in the P/N 464555 unit.

7.2.2 Task Summary

Maintenance records at Dover Air Force Base were reviewed. During an eight-month period three switch failures had occurred. In all three instances, the failure was the result of rotating the switch beyond its limits in a counterclockwise direction.

Two conditions are believed to contribute to this type of switch damage:

- The decals for an adjacent switch are misleading to untrained personnel.
- No mechanical stop is provided to prevent the switch from being rotated beyond its limit in the counterclockwise direction.

7.2.3 Recommendations

Figure 7-1 shows the front panel in its present configuration with the "OUT" decal for the toggle switch in a horizontal plane. Because of its proximity, the "OUT" position appears to be related to the IFF switch rather than the toggle switch.

This confusion can be eliminated, as shown in Figure 7-2, by displaying the "OUT" decal in a vertical plane which will disassociate the position from the IFF switch completely.

An additional safeguard can be provided by mounting a mechanical stop pin to the front panel, as shown in Figure 7-2, which will prevent rotating the switch beyond its intended limits.

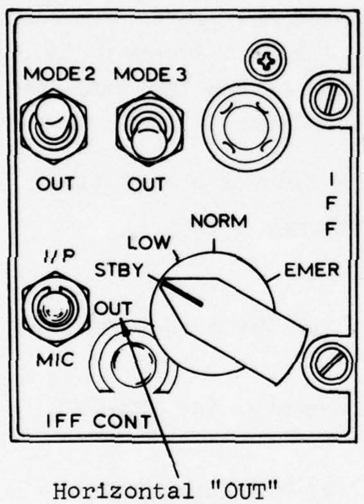

FIGURE 7-1

PRESENT CONFIGURATION OF FRONT PANEL

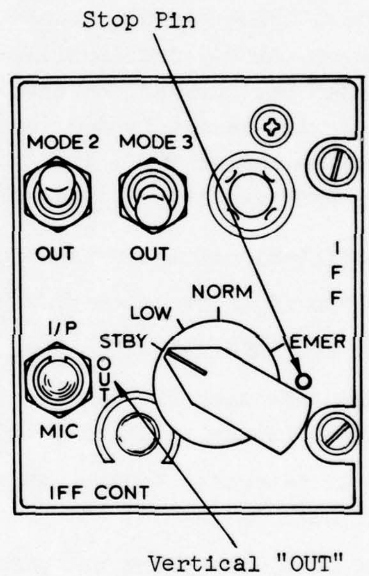

FIGURE 7-2

RECOMMENDED CONFIGURATION OF FRONT PANEL

The decal for the toggle switch can be changed with a minimum of cost and should provide the desired results. The addition of the stop pin is a slightly more complex modification; however, it will eliminate the possibility of damaging the switch by rotating it beyond its limits.

7.3 Evaluation of the Fault Detection Tester (FDT) and IRAM Computer

7.3.1 Task Definition

ARINC Research was directed to review available technical information to define the extent to which the FDT or the IRAM Computer will compensate for deficiencies in the Short System Ground Check (SSGC) and self test as defined in earlier reports.*

7.3.2 Task Summary

One of the tasks assigned ARINC Research under Contract AF 09(603)-60655 was to "determine the effectiveness of the aircraft Short System Ground Check (SSGC) and the Automatic Flight Control System (AFCS) self test to identify a system and/or a unit failure."

The original task was directed to the tests associated with the Automatic Flight Control Group (AFCG), Stable Coordinate Reference Group (SCRG), Air Data Computer Group (ADCG), and Stability Augmentation System equipment. The task assigned under the current contract was to define which of the previously reported deficiencies will be eliminated through the use of the Aircraft Armament Inc. (AAI) Fault Detection Tester (FDT) and through the installation of the Improved Reliability and Maintainability (IRAM) Computer developed by Hughes Aircraft Company.

The technical documents used for reference in this task were as follows:

- Hughes Aircraft Company, Report FD 30678-907, 15 March 1966
- ECP HUG (MA-11ASQ-25) 1447, 22 February 1966
- ARINC Research Problem Report MI-04-5, part of the Twenty-Second F-106 Status Letter, 5 January 1966
- Fault Detection Tester, AN/MPM-54, Aircraft Armaments, Inc. ER-3272 (no date indicated)
- ADC Final Test Report, Project ADC/73AD/64-19, 23 February 1965

7.3.3 Task Findings

7.3.3.1 Short System Ground Check (SSGC)

The Short System Ground Check is designed primarily for rapid GO-NO-GO test of the F-106 AWCIS. In the event of a malfunction, indicated by failure of a test, a fault indication will isolate the malfunction to a subsystem or to an area within a subsystem.

The capabilities of the SSGC were defined in relation to the particular equipment groups under test. In each of these areas the statements of deficiencies are quoted below from the earlier study. Each quotation is followed by a description of the most recent findings.

*ARINC Research Publication 518-01-2-639, Final Engineering Report, Reliability and Maintainability Improvement Program for the F-106 Avionics, 10 July 1966. ARINC Research report on Task MT-04-5 was included in the 22nd F-106 Status Letter.

Stable Coordinate Reference Group (SCRG)

(1) "The SSGC will not detect marginal equipment performance or gyro precession (drift) malfunctions."

More accurate measurement will be possible with the IRAM Computer. This will improve the capability to detect marginal conditions.

(2) "Malfunctions cannot be isolated to a specific unit."

Neither the FDT, nor the new computer change will improve the malfunction-isolation capability.

Automatic Flight Control Group (AFCG)

(1) "The SSGC is not considered to be a valid AFCS test without the use of the Mobile Radiation Test Set (MART cart)."

Maintenance personnel at the bases under ARINC Research surveillance do not, as a general practice, use the MART cart. This factor is not expected to change with availability of the new Computer or the FDT.

(2) "The SSGC will not detect marginal equipment operation in the AFCG."

More accurate measurement will be possible with the IRAM Computer. This increased capability will improve the capability to detect marginal conditions.

Air Data Computer Group (ADCG)

(1) "Air data from the transducers are simulated by the SSGC. As a result, faults in the transducers will not be detected."

Transducer faults can be detected by use of the FDT since the transducers' outputs are checked.

(2) "Improper positioning of analog computer servo mechanisms could not be detected by the SSGC."

The IRAM Computer will provide the capability to detect this type of malfunction.

(3) "Computer malfunctions invalidate the SSGC for the ADCG approximately 50 percent of the time."

The expected high reliability of the new computer will greatly improve this situation.

7.3.3.2 Self Test

No change in the self-test features were indicated in the technical material used in this task.

7.4 Investigation of Ground Loops

7.4.1 Task Definition

ARINC Research was directed to investigate the feasibility of improving the reliability of the stable reference equipment by modification of the grounding and shielding circuitry.

7.4.2 Task Summary

Several problems associated with the 464009, 464109, and 464309 units of the Stable Control Reference Group (SCRG) were identified during earlier contract activities. Initial investigations indicated that interference was being introduced into the system as a result of the grounding and shielding techniques being used.

Laboratory tests conducted by ARINC Research showed that connecting the signal ground to the chassis ground significantly reduced the interference present on the input and output signals. On the basis of these findings, field tests were designed for the three units to determine the feasibility of solving the problem by using this grounding technique. The 464009 unit was selected as the first unit to be tested since the high-gain amplifiers used in this unit were more susceptible to noise than the lower-gain amplifier used in the remaining units.

7.4.3 Conclusions

A variety of changes were tested. The best changes from the viewpoint of cost and complexity of the modification were found to be the following:

- To connect instrument ground to chassis ground
- To connect d-c ground to chassis ground

The overall reduction in interference gained through these wiring changes eliminated the requirement for modifications to the remaining two units (P/N's 464109 and 464309).

7.4.4 Recommendations

It is recommended that the P/N 464009 unit be modified as follows:

(1) Locate the Electrical Components Bracket Assembly, P/N 333016.

(2) Locate the mounting bracket, P/N 333017, and identify the end containing six insulated terminal studs.

(3) Locate the insulated terminal studs identified as E3, E4, and E6.

(4) Connect and solder a suitable length of No. 22 awg black, 19-strand Teflon-wire (MIL-W-16878D Type E or equivalent) between terminal studs E4 and E6 located in Step 3.

(5) Connect and solder a suitable length of No. 22 awg black, 19-strand Teflon-wire (MIL-W-16878D Type E or equivalent) between terminal studs E3 and E6 located in Step 3. This completes the modification.

7.5 Investigation of Rotary-Joint Failures

7.5.1 Task Definition

ARINC Research was directed to determine if rotary-joint failures were a problem at the F-106 bases under ARINC Research surveillance.

7.5.2 Task Summary

At the request of WRAMA engineering a search of maintenance records was conducted at Dover and Tyndall Air Force Bases by ARINC Research personnel. The findings of this search indicate that there was no rotary-joint-failure problem at either of the two bases. On the basis of this finding, WRAMA directed that the task be closed.

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APPENDIX A

PART FAILURE RATES USED IN RELIABILITY PREDICTIONS
FOR F-106 ELECTRONIC SYSTEMS

APPENDIX A

PART FAILURE RATES USED IN RELIABILITY PREDICTIONS FOR F-106 ELECTRONIC SYSTEMS

1. Sources of Data

The part failure rates used in the reliability predictions for the F-106 equipments are presented in Table A-1. All the malfunction rates, except as noted, are based on information contained in ARINC Research Report "Prediction of Field Reliability for Airborne Electronic Systems," 31 December 1962*. Part failure data presented in that report were accumulated by ARINC Research Corporation during surveillance of B-52 aircraft at Walker Air Force Base for a period of nine months ending in March 1962. Equipments represented in the B-52 study were the AN/ARC-34, AN/ARC-65, AN/ARA-25, AN/APX-25, AN/APN-89, AN/APN-89A, AN/ASB-4, and AN/ASB-4A. The part data obtained from other sources, as referenced in Table A-1, are from other airborne equipments studied, or were already modified for the airborne environment. Only the basic part failure rates from the Martin Handbook required special modification for F-106 predictions.

2. Adaptation of B-52 Data to F-106 Equipments

A portion of the given part reliability data accumulated in the B-52 program is in Table A-2. The diversity of B-52 systems (as to types and applications) from which the malfunction rates were derived provide these rates with "built-in" averaging factors, with respect to stress and maintenance conditions, similar to those of the F-106 systems. Therefore, the B-52 data are the most logical choice of available data for application to the F-106 systems.

In the derivation of the part reliability data in Table A-2, it was assumed that in any one maintenance action one part alone was the actual cause of equipment malfunction. Any other part failures reported were considered secondary failures or mishandling accidents during maintenance operations. Thus the data were corrected for clustering effects (i.e., multiple parts actions in any one maintenance action). In addition, the failure-rate data of Table A-2 reflect the effect of adjustments performed during the correction of equipment malfunctions.

In Table A-2 a distinction is made between part failure rate and part malfunction rate, which is the sum of the part failure rate (Column 9) and the part adjustment rate (Column 10). This gives a more realistic rate for adjustable types of parts than otherwise would be obtained. The instantaneous malfunction rates of the various parts were assumed to be constant. Justification for this assumption is rather tenuous for some part types, with respect to the physics-of-failure implications associated with constant malfunction rates; this is

* ARINC Research Publication 203-1-344, Prediction of Field Reliability for Airborne Electronic Systems, 31 December 1962.

TABLE A-1

PART MALFUNCTION RATES FOR RELIABILITY PREDICTIONS OF F-106 ELECTRONIC SYSTEM

Part Category	Malfunctions Per Hour (Multiply by 10^{-6})
Accelerometer	280.00 (1)
Bearing	50.00
Capacitor, Fixed	
Ceramic	0.54
Electrolytic	11.00
Glass	0.70
Mica	0.34
Paper	0.95
Plastic Film	43.60
Tantalum	21.93
Capacitor, Variable	4.74
Chopper	50.00 (1)
Clutch Magnetic	60.00 (1)
Connectors	
Coaxial Plug	7.19
Coaxial Receptacle	6.04
Other Type, Receptacle	0.02/Pin
Other Type, Plug	0.02/Pin + 1.15
Counter, Mechanical	2.44
Crystal, Quartz	3.04
Diode	
Regulator and Rectifier (1A)	17.70 (2)
Low Current (1A)	10.20 (2)
Electron Tubes	
Cathode Ray	705.97
Klystron	1,191.75
Klystron, Adjustable	1,334.76
Magnetron	2,783.02
TR	423.10
Miniature, Amplifier	42.15
Miniature, Rectifier & Gas	100.38
Electron Tubes (continued)	
Subminiature, Amplifier	33.25
Subminiature, Rectifier & Gas	51.44
Filter (Band Pass, Harmonic RF Interference)	2.75
Filter, Mechanical	30.00 (1)
Gear Assembly	90.00 (1)
Gyro	490.00 (1)
Heater	15.53
Inductor	5.15
Meter, Electrical	12.19
Motors	
A-c Blower	142.33
D-c Blower	108.28
Other, A-c	75.82
Other, D-c	7.26
Motor-Generator	216.78
Relays	
Rotary	206.34
Switching	146.87
Time Delay	82.40
Rectifier, Selenium	12.71
Resistor, Fixed	
Wirewound	9.15
Other	0.79
Resistor, Variable and Potentiometers	
Carbon Composition	297.60
Carbon Film	536.85

TABLE A-1 (Continued)

Part Category	Malfunctions Per Hour (Multiply by 10^{-6})	Part Category	Malfunctions Per Hour (Multiply by 10^{-6})
Resistor, Variable and Potentiometers (continued)		Synchros	
Wirewound	336.19	Resolver	103.28
Wirewound, Infinite Resolution	613.35	Other	26.10
Socket	0.43 (3)	Thermister	60.00 (1)
Solenoid		Transformers	
Axial	30.87	High Voltage	31.10
Rotary	227.00	Power and Filament	2.27
Switch		Other (IF, Audio, etc.)	1.34
Cam	1,448.26	Transistors	
Commutator Type	1,568.57	High Power (5w)	20.30 (2)
Microswitch	73.32	Low Power (5w)	7.50 (2)
Pushbutton	56.52	Wave Guide	
Rotary	8.40	Fixed	110.00 (1)
Sliding Action	73.32	Flexible	284.00 (1)
Thermostat	2.72	Rotary Joints	127.00 (4)
Toggle	4.09		

(1) "Reliability Application and Analysis Guide," The Martin Company, July 1961.

(2) "Semiconductor Reliability," final report under Contract NObsr-87664, ARINC Research Publication 239-01-4-383, 31 July 1963.

(3) "Operational Reliability Estimates and Part Failure Rates for Naval Avionics Equipments," ARINC Research Publication 202-1-331, 15 November 1962.

(4) "A Preliminary Study of Microwave and Transmitting Tubes, Semiconductors, Relays, and Other Parts," ARINC Research Publication 123-6-189, 30 September 1960.

Notes: (a) A gear assembly is considered to be equivalent to six gears or less and associated parts.

(b) Fuses will not be included in part counts.

(c) Lamps will not be included in part counts.

		TABLE A-2* PART RELIABILITY DATA FOR AIRBORNE ELECTRONIC SYSTEMS								
		Observed Data				Computed Estimates				
1	2	3	4	5	6	7	8	9	10	11
Part Category	Part Type	Part Hours, T_1 (Millions)	Parts Replaced	Parts Repaired	Parts Adjusted	Parts Failed	Parts Requiring Adjustment	Failures per Hour (multiply by 10^{-6})	Required Adjustments per Hour (multiply by 10^{-6})	Note References
		On-Off Cycling Rate = 0.15 per Hour				Normalized for Zero On-Off Cycles and Corrected for Clustering				1
Electron Tube (continued)	Subminiature, Ampl. (a)	0.929	606			33.1		6.66		5, 6
	(b)	5.907	58			12.4				
	Subminiature, Rect. & Gas (a)	0.327	200			10.9		10.3		
	(b)	0.734								
	Other, Ampl. (a)	0.241	351			19.2		60.7		
	(b)	0.364	82			17.5				
	Other, Rect. & Gas (a)	0.086	18			1.0		11.2		
	(b)	0.191	10			2.1				
Filter	Band pass	0.163								2
	Harmonic	0.038								
	R.F. Interference	1.054								
Heater	-	1.159	12			3.6		3.11		
Inductor (fixed & variable)	All	7.961	28			8.4		1.06		
Meter & Counter	-	0.284								2
Motor	Blower, AC	0.158	15			4.5		28.5		
	Blower, DC	0.069	5			1.5		21.7		
	Motor & Pump, AC	0.079	3			0.9		11.4		
	Servo or Set, AC	0.813	36	6		12.6		15.5		
	Servo or Set, DC	0.378	1	1		0.6		1.59		
	Timing or Clock, AC	0.017	1			0.3		17.6		
	Timing or Clock, DC	0.038								2
Motor Generator	-	0.705	102			30.6		43.4		
Relay	Rotary	0.138	19			5.7		41.3		
	Switching	4.474	320	2		96.6		21.6		
	Switching, dry circuit	0.940	209			62.7		66.7		
	Time Delay	0.127	7			2.1		16.5		

NOTES FOR TABLE A-2

1. Values in the normalized columns must be modified to include the effects of on-off cycling by multiplying the values by the term $1 + 8N$, where N is equal to the expected number of on-off cycles per operating hour.

2. No replacements or repairs were observed for this part type. As a conservative estimate of the failure rate, $\hat{\lambda}_1$, the upper 50% confidence limit on zero observations may be used. This value is computed by the equation

$$\hat{\lambda}_1 = \frac{0.693 \times 10}{\text{Observed part hours}}$$

The corresponding confidence statement is $P(0 \leq \lambda_1 \leq \hat{\lambda}_1) = 0.50$.

3. The 'part hours' shown on this line are pin and socket hours for the plugs and receptacles. Correspondingly, the value in column 9 represents the rate of plug and receptacle failure per pin and socket hour. To obtain the estimated failure rate for a plug, therefore, the number of pins is multiplied by 0.02; similarly, for a receptacle, the number of sockets is multiplied by 0.02.

4. The adjustment data for this category has been presented on a separate line since it pertains only to plugs. For the malfunction rate of plugs, the adjustment rate must be added to the failure rate; the malfunction rate of receptacles is equal to the failure rate alone.

5. Letters (a) and (b) refer respectively to parts groups 1 and 2 as defined in Table A-2.

6. Refer to Section 3, Part B of the report proper for optional procedure for modifying the replacement/repair/failure values (columns 4,5,7 and 9) of this part type to account for abnormal stress and operating conditions. See page 6 of the report for remarks concerning the optional nature of these modifications.

*Abstracted from ARINC Research Corporation Publication 203-1-344, Prediction of Field Reliability for Airborne Electronics Systems, 1962.

especially true for part types that exhibit strong mechanical wearout characteristics. This should not, in general, cancel the value of the failure rates, except in chance circumstances where a severely unfavorable combination of parts should appear.

In developing the part malfunction rates for the F-106 equipments, data for a number of similar parts, with similar malfunction rates, were combined.

Regarding the part types that exhibited no malfunctions in the B-52 surveillance, when data on these were used for compiling malfunction rates for application to F-106 equipment predictions, Note 2 of Table A-2 was taken into consideration.

To account for the deleterious effect of different equipment on-off cycling rates the B-52 data were modified by the factor 1 + 8N, where N is the number of on-off cycles per hour. The factor for the F-106 calculated to be a value of 5 (N = 0.5 cycles per hour).

3. Use of Other Part-Reliability Data Sources

Part malfunction rates listed in Table A-1, which are not based on B-52 data, are representative of airborne environments. However, no attempt was made to modify the original data, to account for clustering and cycling effects, as was done for the B-52. Factors were used to transform the values for airborne environment use when the data were not originally generated as such.

Operate hours and removal data, from which the semiconductor malfunction rates were derived, are summarized in the following:

Semiconductor Category	Operate Hours (in millions)	Number of Removals	Removals per Million Hours
High-power transistors (P 5w)	9.05	184	20.3
Low-power transistors (P 5w)	78.2	586	7.5
High-current diodes (1 amp)	66.4	1,146	17.2
Low-current diodes (1 amp)	66.4	708	10.7

As indicated above, the malfunction rates used for semiconductors were listed in the source information as removal rates. Thus it is possible that these rates might be somewhat pessimistic, or high.

Available information regarding the remaining parts listed in Table A-1 is as follows:

Part Type	Operate Hours	Number of Failures or Removals	Removal or Malfunction Rate ($\times 10^{-6}$)	Source
Accelerometer	*	*	280.00	Reference 1 of Table A-1
Bearing	*	*	50.00	Reference 1 of Table A-1
Chopper	*	*	50.00	Reference 1 of Table A-1
Clutch, Magnetic	*	*	60.00	Reference 1 of Table A-1
Gear Assembly	*	*	90.00	Reference 1 of Table A-1
Gyro	*	*	490.00	Reference 1 of Table A-1
Wave Guide, Fixed	*	*	110.00	Reference 1 of Table A-1
Wave Guide, Flexible	*	*	284.50	Reference 1 of Table A-1
Rotary Joints	55,000	7	126.70	Reference 4 of Table A-1
Sockets	4,639.083	2	0.43	Reference 3 of Table A-1

*Unknown. Malfunction rates were determined by multiplying generic failure rate by a factor of 100. Both the generic rates and multiplying factors are given in Reference 1 of Table A-1.

APPENDIX B

AN OPTIMUM STRATEGY FOR
SINGLE-UNIT SEQUENTIAL TESTS

APPENDIX B

AN OPTIMUM STRATEGY FOR SINGLE-UNIT SEQUENTIAL TESTS

1. Introduction

In section 6.6.7.1 of the text it was concluded that revision of troubleshooting strategies would not be worthwhile under present operational constraints, because the cost would far outweigh the benefits to be realized. This appendix describes a method for determining the optimum troubleshooting strategy.

2. Problem

When a symptom of a failure is reported to a maintenance technician, he must repair the failed equipment by replacing a faulty line-replaceable unit (LRU). Either he removes a suspect LRU from the equipment and replaces it with an LRU from the spares supply, sending the removed LRU to the shop for repair, or he removes the suspect LRU and immediately takes it to the shop for checkout and repair, so that it can be reinstalled in the plane. In either case, the technician needs a method that tells him in which order LRUs should be removed to try to clear the symptom. Such a method now exists; it is a branching strategy, in which the technician selects a starting point by referring to the symptom report and follows the procedure through successive decisions until the malfunction is corrected.

With each removal, check, and replacement, there can be associated a cost, equipment utilization, manpower, and related factors. The history of failures with the same symptom permits an estimate of the possibility that any particular LRU is the bad one. The assumption is made, for purposes of this analysis, that the failure is in a single LRU. It is desired to order the actions of the maintenance man so that the repair can be accomplished at the lowest possible cost.

3. Solution

For any given symptom and any LRU, there is a probability that the LRU is causing the failure. If there are n LRUs in the equipment, $P_1, P_2 \ldots P_n$ must be known, where P_i = probability that LRU number i is bad. C_i -- the cost of removing, testing, and replacing the i^{th} LRU -- must also be known.

It is proposed that to minimize cost, the first LRU chosen for a check should be the one with the lowest ratio $\frac{C_i}{P_i}$; the next LRU chosen should have the next lowest ratio $\frac{C_i}{P_i}$; etc.

Suppose there are n LRUs (b_1, b_2 . . . b_n). Let one strategy be an ordering of the LRUs for checking: $S_1 = b_{11}, b_{12}, b_{13} \ldots b_{1n}$ (there are n! strategies). Now, for each strategy S_1, there correspond two strategies S_1^* and S_1', defined as follows:

$$S_1^* \text{ (the inverse of } S_1) = b_{12}, b_{11}, b_{13}, b_{14}, b_{15} \ldots b_{1n}$$

$$S_1' \text{ (the complementary part of } S_1) = b_{13}, b_{14}, b_{15} \ldots b_{1n}$$

Let

X_1 = the expected cost of S_1

X^*_1 = the expected cost of S_1^*

X = the expected cost of S_1' in S_1

(i.e., that part of X_1 due to S_1')

The costs of strategies can then be computed as follows:
Suppose that in S_1,

$$\frac{C_{11}}{P_{11}} < \frac{C_{12}}{P_{12}}$$

Then

$$X_1 = C_{11} + (1 - P_{11})\, C_{12} + X_1' \text{ (see below for determination of X)}$$

That is, b_{11} is always checked, at cost C_{11}; b_{12} is checked a fraction $(1 - P_{11})$ of the time, at cost C_{12}; etc.

$$X_1^* = C_{12} + (1 - P_{12})\, C_{11} + X_1$$

Then

$$X_1^* - X_1 = C_{12} + (1 - P_{12})\, C_{11} - C_{11} - (1 - P_{11})\, C_{12}$$

$$X_1^* = X_1 = C_{12} + C_{11} - P_{12}C_{11} - C_{11} - C_{12} + P_{11}\, C_{12}$$

$$= P_{11}\, C_{12} - P_{12}\, C_{11}$$

From the assumption that

$$\frac{C_{11}}{P_{11}} < \frac{C_{12}}{P_{12}},$$

it follows that

$$C_{11} P_{12} < C_{12} P_{11}$$

Then

$$X_1^* - S_1 > 0$$

Thus it is shown that, for any given strategy after removal of the first two LRUs, the lower cost is achieved by choosing first the LRU with the lower $\frac{C}{P}$ ratio. The best strategy, then, will choose first the LRU with lowest $\frac{C}{P}$ ratio. The same argument is applied to subsequent choices.

The expected cost of S_1 is given by

$$S_1 = C_{11} + (1 - P_{11}) C_{12} + (1 - P_{11} + P_{12}) C_{13} \ldots .$$

$$+ (1 - \sum_{R-1}^{j-1} P_{1k}) C_{1j} + \ldots .$$

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